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Reservoir Control Center

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Missouri River Main Stem Reservoirs

Missouri River Stage Trends

RCC Technical Report S-98

Missouri River Basin

MISSOURI RIVER STAGE TRENDS

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INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to present the data used and results of the update of the Missouri River stage trends analysis. Trends in river stages are presented for tailwater locations, the navigation channel and headwater locations. Tailwater locations are subject to scour, generally resulting in a lowering of the river stages over time. Headwater locations are subject to sediment deposition, resulting in an increase in river stages over time. Locations along the navigation channel are subject to a variety of factors which can cause increases or decreases in stages over time.

Stage records for the Missouri River are available for almost 100 years for each of the eight key main stem gaging stations below Sioux City. Although a few isolated discharge measurements were made in the early years, it was not until 1929 that collection of systematic and continuous discharge records by the USGS began. It was at about this same time that construction of river improvement works was initiated to stabilize and channelize the river. An analysis of the effects of these works on Missouri River levels was completed by a consultant's board in the mid-1950's. The board's report of November 1955 concluded that the navigation and stabilization works may have caused an increase in stages near bank full discharge of not to exceed 2 feet between Omaha and the mouth, and possibly as much as 1 foot from Omaha to Sioux City.

The board also expressed the opinion that the low water stage of the Missouri had been lowered on the order of 1 foot. Since publication of that report, the main stem reservoirs have been completed and have significantly altered the flow regime throughout most of the length of the Missouri River. The control of floods and the supplementation of low flows by these main stem and tributary reservoirs have undoubtedly contributed to changes in the stage-discharge relationship on the Missouri River during the past 30 to 40 years, but no attempt has been made in this report to differentiate between the effects of this control and those exerted by the river control works or by other encroachments in the flood plain or natural events.

A similar report titled "Missouri River Stage Trends, MRD-RCC Technical Study S-72" was published in September 1972 and updated in June 1975, August 1981, December 1985, and September 1987. This updated report is published as MRD-RCC Technical Report C-96.

MISSOURI RIVER LENGTH CHANGE

Since 1890 the length of the Missouri River between Sioux City and the mouth has been shortened by about 75 miles (almost 10 percent). However, two-thirds of this shortening has been concentrated in two reaches, including the reach between Sioux City to Omaha and between Kansas City to Waverly. This shortening has undoubtedly contributed to the lower stage trend which is evident at these two stations. The Missouri River lengths between the main stem stations for the years 1890, 1941, and 1960 are given in table 1.

Table 1
Missouri River Channel Lengths

Stations	Missouri River Length Between Stations - in Miles			1890-1960 Length Change	
	1890	1941	1960	Miles	%
Sioux City to Omaha	147.7	128.0	116.4	-31.3	-21.2
Omaha to Nebraska City	52.1	52.7	54.0	1.9	3.6
Nebraska City to St. Joseph	129.0	119.3	114.0	-15.0	-11.6
St. Joseph to Kansas City	88.0	82.5	81.8	-6.2	-7.1
Kansas City to Waverly	91.5	80.3	72.7	-18.8	-20.5
Waverly to Boonville	93.8	101.0	96.8	3.0	3.2
Boonville to Hermann	101.9	99.3	98.7	-3.2	-3.1
Hermann to Mouth	103.5	96.9	97.9	-5.6	-5.4
Total (Sioux City to mouth)	807.5	760.0	732.3	-75.2	-9.3

SOURCE OF DATA FOR STAGE TREND ANALYSES

Stage trends, observed in the main stem reservoir tailwaters, and at each of the nine Missouri River gaging stations for four to eight discharges, are presented on Figures 1 through 22. The discharges shown for the gaging stations range from 10,000 cfs to 500,000 cfs, depending on the station.

The sources of data for these figures were the compilations of rating curves which were initially prepared in the early 1950's in connection with the consultants' study of the effects of the navigation and stabilization works. These rating curve compilations have been kept up to date since that time by continued annual submission of flow measurement data and rating curves by each District. The open-water rating curves presented for each station along the navigation channel are frequently seasonal in nature, being a foot or two higher in the summer than in the spring and fall. The discharge measurement points which defined the summer rating curve were given the most weight in developing the stage trends. The stage data used in developing the stage trend curves for the stations along the navigation channel were selected more on the basis of a personal appraisal of the discharge measurement values than on the rating curves presented. Data were also obtained for headwater and tailwater locations from published Corps reports and memoranda.

TAILWATER STAGE TRENDS

The release of the essentially sediment free water through the Missouri River Main Stem dams has resulted in a lowering of the downstream tailwater elevation. Pre-construction estimates predicted that the water surface elevations immediately downstream of the dams would lower a maximum of 15 feet at each project where no fixed downstream control existed. Turbine elevations were set to account for this eventual lowering. At Big Bend Dam, the tailwater elevations are controlled by the Fort Randall pool immediately downstream. Oahe Dam discharges into a short reach of open river before entering the headwaters of Bend Reservoir. The Fort Peck, Garrison, Fort Randall, and Gavins Point projects discharge directly into open river channel reaches that lie in alluvial deposits. Tailwater trends are monitored annually at all of the projects and are discussed in the following paragraphs.

FORT PECK

Construction of the Fort Peck project began in 1933. Closure was made in 1937, and the project was placed in operation for purposes of navigation and flood control in 1938. Power plant number 1 at Fort Peck became operational in 1943, with the second power plant coming on line in 1961. Because of the location of the two power plants the stage discharge rating relationship is quite complex at this location since the tailwater stage at either power plant is a function of the discharges at both power plants. Prior to 1956, Fort Peck was the only main stem project with a significant amount of accumulated storage. As a consequence, releases in the 28,000 cfs range were frequently required for navigation with a maximum mean daily rate of 28,600 cfs in 1948. Since late 1956, with the exception of 1975, releases have not been significantly in excess of the power plant capacity of the project, amounting to about 15,000 cfs after the second power plant was on line. Previous studies have indicated that the tailwater rating curve has been stable since about the 1960's. Because of the complex relationship to define the tailwater rating curve at Fort Peck and the apparent stability in the relationship, no updates to the rating curve have been made since 1966. Therefore, the tailwater stage trend could not be evaluated at Fort Peck project for this update.

GARRISON

In 1946, construction of the Garrison project was initiated. Closure was made in 1953, with power plant operation on line in 1956. Since 1956, outflows from Garrison have generally been through the power facilities, having a maximum capacity of about 38,000 cfs. An exception was in 1975 when outflows of 65,000 cfs were required for over 1 month as a result of record high upstream runoff. Figure 1 shows tailwater rating curves developed at 5-year intervals beginning in 1955 and extending through 1995. As illustrated by those curves, a dramatic lowering has occurred at each 5-year interval with each curve dropping about 1 to 2 feet until about 1980. From 1980 to 1996 the total shift was approximately 1 foot . This figure also shows an increased rate of tailwater lowering for discharges in excess of 20,000 cfs. The increased rate is attributed to the magnitude of project releases experienced during 1997. Figure 2 shows the trend over time of the tailwater stage for discharges ranging from 10,000 cfs to 40,000 cfs. As shown by those graphs, there has been a lowering of the tailwater stage by about 9 feet since closure of the dam. Since about 1980, the trend has been more stable, decreasing at a rate less than 0.1 foot per year.

OAHE

Diversion and closure of Oahe were completed in 1958 following about ten years of construction that was initiated in 1948. In April 1962, the first power unit came on line with all units operational in July 1966. Tailwater rating curves developed at 5-year intervals beginning in 1965 and extending through 1995 are compared on Figure 3. As shown on those curves, there has generally been about 1 foot or less change in tailwater stages over the years. Construction of channel block No. 6 was completed in June 1967 with an extension to River Island completed in July 1970. As shown by the change in tailwater stage from 1965 to 1970, construction of channel block No. 6 appeared to increase the tailwater stage. It should also be noted that the Big Bend power plant became fully operational in 1966 with Lake Sharpe pool levels being maintained near the normal operating level of elevation 1420 feet m.s.l. From 1970, there appeared to be a trend towards lower tailwater stages except for upward stage shifts occuring in the 1982 to 1984 and 1993 to 1995 periods. Time trend plots for discharges ranging from 10,000 cfs to 50,000 cfs are shown on Figure 4.

BIG BEND

Big Bend discharges directly into the Fort Randall pool. Consequently, tailwater stages are influenced by Fort Randall pool elevations. Therefore, no stage trend analysis was completed for Big Bend.

FORT RANDALL

Construction of the Fort Randall project was initiated in 1946, with closure made in 1952. Initial power generation began in 1954 with the final unit on line in 1956. As shown on Figure 5, a lowering of the tailwater stage of about 5 feet has occurred over a 40 year time span. It should be noted that the 1994 through 1997 trend lines shown on that figure have been adjusted to account for a 1 foot shift in the gage datum. During 1994, it was determined that the tailwater gage at Fort Randall has been recording water surface elevations one foot lower than the actual water surface elevations. The source of the error is not known at this time, but may have occurred in the 1979 to 1980 time period, which corresponds to a significant decrease in the stage trend curve shown on Figure 6. On that figure, stage trends are shown for discharges ranging from 10,000 cfs to 40,000 cfs. Stages prior to 1994 have not been adjusted to account for the 1 foot shift in gage datum.

GAVINS POINT

The Gavins Point tailwater has lowered about 10 feet since closure of that project in 1955. The rate of degradation has been reasonably constant, except for the increased rates observed for the first 2 years after closure and during high flow in the mid-80's. Stages remained relatively constant during the low release years of the 1987 to early 1993 drought. The high flow years from 1995 through 1997 has resulted in an increase in the rate of tailwater lowering experienced below Gavins Point Dam. In the 1949 Gavins Point Definite Project Report, ultimate degradation of about 15 feet was projected and allowed for in the design of the project structures. The rate of expected degradation was not specified. Figure 7 shows the Gavins Point tailwater rating curves, while Figure 8 shows the Gavins Point tailwater trends for the 10,000, 20,000, and 35,000 cfs discharge levels.

PROJECT COMPARISONS

A comparison of tailwater trends for the Gavins Point, Fort Randall and Garrison projects is shown on Figure 9. As illustrated on that figure, it appeared the trend in tailwater stages had become more stable 30 years following closure of the dams. Since that time, there has been only a small decrease in tailwater stages at the Garrison and Fort Randall projects, however the Gavins Point project has experienced an increased rate of tailwater lowering following the high flow years of 1995 through 1997. Total decrease in tailwater stage at those projects ranges from about 7 feet at Fort Randall to about 10 feet at Gavins Point.

NAVIGATION CHANNEL STAGE TRENDS

Downstream from Gavins Point Dam the Missouri River remains in a natural state for a distance of about 59 miles in which it is free to meander throughout a wide flood plain. Between Ponca, Nebraska, and Sioux City, Iowa, the river is confined by revetment and dike structures into a single channel developed for bank stabilization. The Missouri River navigation channel extends for 735 miles from near Sioux City, Iowa, to the mouth near St. Louis, Missouri. It varies in width from 600 feet at Sioux City to 1,100 feet at the mouth near St. Louis. Flow regulation by the reservoir system has substantially changed the discharge regimen. Although the average annual discharge at Sioux City has not changed appreciably, maximum flood peaks have been significantly reduced, low flows increased and the distribution of the annual runoff altered substantially. The reservoirs have also had a profound effect on downstream sediment loads. In the natural river, the average annual sediment load at Gavins Point was about 135 million tons per year. With dam closure, virtually all the incoming sediment was entrapped in the reservoirs and the sediment loads just below the dam sites were reduced essentially to zero. This along with other effects including deposition of sediments on berms, channel cutoffs, and construction of levees have contributed to changes in stages at downstream stations. Trends at each of the key locations are discussed in the following paragraphs.

SIOUX CITY

As illustrated quite clearly on Figure 10, the predominant stage trend at Sioux City has been downward. At normal discharge levels, this downward shift of 7 to 10 feet since 1955 is essentially the same magnitude as what has occurred in the Gavins Point tailwaters during the same period. Since degradation of this magnitude has not progressed to this extent through the Gavins Point-Sioux City reach, it is apparent that a combination of factors is responsible for this marked reduction in stages at normal to lower flows. Stage reductions, however, have slowed significantly from those experienced in the 1960's and early 1970's and appear to be stabilizing for normal flows. Until June of 1984, when tributary flow caused Sioux City to reach 103,000 cfs, flood control regulation of the main stem reservoir system had limited Sioux City flows to less than 100,000 cfs since closure of Gavins Point in 1955.

Stage reductions at Sioux City have caused numerous problems at marinas and dock facilities. These problems were magnified during the 6-year drought of the late 1980's and early 1990's when less than full service navigation flows were provided. This was also true in cutoff lakes, such as at Miners Bend, where the combination of sedimentation of the lake and degradation in the river has cut off access to the Missouri River. The reduction of the navigation season discharge from 31,000 to 25,000 cfs, which was necessary during the drought, resulted in Sioux City stages of about 2.5 to 3 feet below the river levels experienced during normal navigation releases from Gavins Point dam. During the drought years 1987 to early 1993, the stage trend at Sioux City rose about a foot due to the lower than normal flows. High flows, up to 72,000 cfs, during the summer of 1993

reversed the trend. The succession of high flow years 1995, 1996 and record breaking 1997 has resulted in a sharp reduction in Sioux City stages. The provisional data of 1998 indicates that since 1995, approximately an additional 3 foot of stage reduction has occured.

OMAHA

Missouri River stages at Omaha have reversed in recent years. As shown on Figure 11, the overall stage trend between the mid-1930's and the early 1950's was downward, totaling about 5 feet. However, since the mid-1950's, no significant changes have been noted, particularly at normal discharges. The lowest stages for normal discharges occurred following the 1952 flood. Since that time, stages have actually risen a foot or two. At below normal discharges, 10,000 to 20,000 cfs, stages rose a couple feet between 1952 and the mid 1960's. Since then, the stages have dropped once more returning to the levels reached in the early 1950's or lower. At 10,000 cfs stages are about 2 feet lower than in the early 1950's.

At 60,000 cfs, high stages were experienced in the late 1930's, followed by a gradual fall totaling about 5 feet by the mid-1950's. Between the mid-1950's and mid-1960's the stages recovered approximately 4 feet and have risen only slightly since then. At 100,000 cfs, high stages were also experienced in the late 1930's, followed by a gradual fall of about 4 feet by the mid-1950's. Stages had risen to their former high level by the mid-1970's and rose another 2 feet by 1993 before falling back with the high flows of the late 1990's.

NEBRASKA CITY

Three different stage trends are noted on Figure 12 at the Nebraska City gage, with increasing stages between 70,000 and 100,000 cfs, moderately lowering stages at 20,000 cfs, and at normal flows of 30,000 to 40,000 cfs, relatively constant stages.

The channel capacity of the Missouri River at flood stage at Nebraska City, has been reduced from about 150,000 cfs to perhaps 90,000 cfs. An overall rise in stage of 5 to 6 feet has occurred for a discharge of 100,000 cfs. Based on 1994 data, the flood of 1993 reduced stages roughly 1 foot at Nebraska City for 70,000 and 100,000 cfs and 0.5 foot for the remaining discharge levels. These decreases appear to have returned to pre-1993 trends based on observations through 1997.

Most of the flood plain of the Missouri is protected by levees in the Nebraska City reach, but agricultural pursuits riverward of the levees and in low-lying unprotected or under protected areas are vulnerable to flooding from the tributaries with only normal releases from Gavins Point. Interior drainage problems occur in this area and have worsened due to the increasing river stages at above normal flow levels.

ST. JOSEPH

Stages at St. Joseph for 20,000 and 40,000 cfs have remained relatively constant except for an upward trend in the rating curve of about 2 feet in 1952 when the 1952 flood caused the St. Joseph cutoff upstream of the gage. In the early 1970's, stages for these discharges declined 1 to 2 feet. Since the flood of 1993, stages fell about 1.5 feet for the 20,000 and 40,000 cfs as shown by the data through 1997 on Figure 13. The stage trends for 70,000 and 100,000 cfs have been generally upward. At 70,000 cfs, the overall rise in the Missouri River stage has been about 2 to 3 feet since the 1940's and about 5 feet at 100,000 cfs. These stage rises are considerably more than can be attributed to the cutoff alone. The stage at 70,000 cfs, which had been relatively constant over the past 20 years, took a sharp fall amounting to almost 2 feet following the 1993 flood. However, for 100,000 cfs the resulting stage during the 1993 flood was roughly 1 foot higher. Based on the 1995 observation, it appears that the stage is returning to previous trends at these discharges.

KANSAS CITY

Missouri River stage trend at Kansas City is consistently downward at all discharge levels up to 100,000 cfs as shown on Figure 14. This trend, which is counter to trends at stations immediately upstream and downstream, began in about 1940. It was likely influenced by downstream channel cutoffs which have shortened the downstream reach by about 20 percent since 1890. Stages, in general, average 7 to 8 feet lower than in the 1930's for 20,000 and 40,000 cfs and 3 to 5 feet lower at 70,000 and 100,000 cfs. Kansas City stages for 40,000 and 70,000 cfs recovered 1 to 2 feet during the drought years of 1987 to early 1993, but then declined dramatically following the 1993 flood with some recovery since. Stage estimates for 1997 indicate about a 2 foot drop in stages from the 1993 pre-flood conditions. Stages at 100,000 cfs have been relatively stable since the late 1950's. Stage observations in 1995 indicated a recovery to the pre-1993 trend following the dramatic shift after the 1993 flood.

At 200,000 cfs, as shown on Figure 15, stages have been slightly rising since the 1950's with a 2 foot stage increase experienced since 1950. Sufficient data are not available to establish reliable trends at flows of 300,000 cfs or higher, although 1993 data indicates there has been a rather significant stage increase, on the order of 4 to 5 feet since the early 50's for discharges at and above 300,000 cfs.

WAVERLY

The Waverly stage trend is generally, 3 to 5 feet upward at the 200,000, 100,000, and 70,000 cfs discharge levels experienced during the 1930's. At 40,000 cfs, stages have risen about 2 to 3 feet since the 1930's. The river stage for a discharge of 20,000 cfs have been nearly constant since about 1955. However, following the 1993 flood, stage reductions of less than a foot occurred for flows in the 40,000 to 100,000 cfs range as shown on Figure 16. Figure 17 displays the stage trends for discharges of 200,000 cfs and above. The upward trend appears to be continuing although the data at discharges in this range are sparse and highly varriable.

BOONVILLE

Stages have remained relatively constant at this station for flows between 40,000 cfs and 100,000 cfs. Short term variations of plus or minus 1 foot over a 4 to 5 year period have been observed, but these changes are minor compared to changes at other stations on the river. Following the 1993 flood stages at normal flow levels appear to be about 1 foot lower than pre-flood conditions. The data available for the higher discharges of 200,000 cfs and 300,000 cfs demonstrate an upward trend of 2 to 4 feet. Figures 18 and 19 show the stage trends at Boonville.

HERMANN

An overall upward stage shift of about 1 to 3 feet was observed from the mid-1930's through the late 1950's for flows of 200,000 cfs and less. However, for about 10 years following the late 1950's, the stage trend flattened and in recent years (1970 to present) has reversed with a downward trend for discharges of 100,000 cfs and lower. At the 300,000 cfs discharge level, a 3 to 4-foot increase in stage has been noted prior to the 1993 flood. Post 1993 flood recovery data have demonstrated a downward trend. The data available for 400,000 cfs and 500,000 cfs indicate an upward shift of approximately 4 to 5 feet. Figures 20 and 21 show the stage trends at Hermann.

HEADWATER AREA STAGE TRENDS

There are two characteristic types of sediment deposits in reservoirs along alluvial rivers: 1) those occurring generally over the reservoir bottom, mostly composed of the finer fractions of the river sediment load, and 2) those occurring in a characteristic delta formation at the head of the reservoir, including all the coarser fractions of the river sediment load. Delta formation in the headwaters area of the reservoir can extend upstream from the reservoir and can cause the reservoir backwater effect to progress upstream, increasing river stages. Headwaters areas of several of the main stem reservoir projects have been experiencing aggradation problems. Stage trends at several of the problem areas are discussed in the following paragraphs.

WILLISTON

The Garrison headwaters extend upstream past the city of Williston, North Dakota, to near the confluence of the Yellowstone and Missouri Rivers. Levees, constructed by the Corps, protect Williston from the aggradation backwater effects. Due to aggradation effects and rising river stages, the level of protection of the levee has been decreasing. An aggradation study of the Lake Sakakawea Headwaters was completed by the Corps in September 1990.

It has been observed that aggradation and delta formation has occurred in Lake Sakakawea headwaters since construction of the Garrison Dam project in 1953 and the filling of Lake Sakakawea in about 1965. Lake Sakakawea backwater and aggradation effects resulted in a dramatic rise in the stage-discharge rating curves for the period 1966 to 1972 and then subsequently a more moderate increase rate that appears to be ongoing to the present. In the reach associated with the City of Williston, the rate has recently been in the order of one foot rise per seven to eight years. For the reach associated with the Buford-Trenton Irrigation District upstream from Williston, the rate is about one foot per six to seven years.

Buildup of the Lake Sakakawea headwaters delta appears to be occurring at a relatively uniform rate (by depth of sediment deposit) over the reach from River Mile 1520 to 1550. This includes the City of Williston which lies at about River Mile 1544. Between 1969 and 1987, the average depth of sediment deposit in this reach has risen about six feet total or about 0.3 feet per year. In the immediate vicinity of Williston, approximately 4 feet of sediment deposition has been measured from 1969 to 1987 or about 0.2 feet per year.

BISMARCK

Bismarck, located in the Oahe headwaters area, is the only station on the Missouri River within the main stem reservoir system for which the aforementioned rating curve analyses and records have been maintained. As shown on Figure 22, there have been no marked changes in stage at this station, except for discharges of 30,000 cfs or greater, which have exhibited a slight upward trend. Past operational problems have been experienced in this area during the winter at housing developments located in the Missouri River bottom lands near Bismarck. A study completed by the Corps in 1985 “Oahe - Bismarck Area Studies” indicated that aggradation has reduced the size of the channel in the study area, resulting in higher stages for the same discharge. The study concluded that for discharges of 50,000 to over 100,000 cfs, the stages have increased by 1 to 2 feet in the study area. It was also estimated that future aggradation will further increase stages for those discharges by an additional 0.8 to 1.4 feet.

PIERRE

Lake Sharpe headwaters extend to the Pierre and Fort Pierre area. Sediments deposited from the Bad River which enters the headwater area at Fort Pierre, have averaged over 3 million tons per year and have caused significant aggradation in this area. A study completed by the Corps in 1988 indicated that river stages have increased by about 1.1 feet for open water discharges of 70,000 cfs and will continue to increase by another 0.5 feet due to future aggradation. That study also indicated that the increase in ice-affected stages has been more severe than the increase in open water stages, resulting in an increase of about 2 feet. From 1963 to 1983, the channel between LaFramboise and Farm Islands has undergone aggradation of from 2 feet on the overbank to 10 feet in the channel.

SPRINGFIELD

Headwaters of the Gavins Point project extend upstream of the Springfield, South Dakota area. Sediment deposition in the vicinity of Springfield has restricted access to Lewis and Clark Lake from the Springfield boat ramp during periods of low lake elevation. Farther upstream, a large delta continues to develop near the mouth of the Niobrara River. This sediment deposition from Niobrara to Springfield has increased river stages in this reach. A water surface profile for a steady discharge of 35,000 cfs obtained in 1994 from upstream of Verdel, Nebraska to below the mouth of the Niobrara River was higher than a water surface profile obtained in the mid-1980's with a discharge of 44,000 cfs which, in turn, was higher than a the profile with a discharge of 60,000 cfs in 1975.

A study was completed by the Corps and published in September of 1992 “Sedimentation near the confluence of the Missouri and Niobrara Rivers 1954 to 1990.” That study found that there has been an overall reduction in channel depth of approximately 3 to 5 feet downstream of the confluence of the Niobrara and 2 feet upstream of the confluence between 1954 and 1984. This change in channel depth has caused increase in stage of about a six feet downstream from the confluence for a discharge of 20,000 cfs. This increase has been at an average rate of about 0.2 feet per year. The most rapid increase in stage occurred between 1957 and 1960 when the stage for 30,000 cfs rose approximately 3 feet. A large flood on the Niobrara occurred in 1960 with discharges exceeding 40,000 cfs resulting in extensive sediment deposition on the Niobrara River delta.

Further upstream, at Verdel, located approximately 5 miles upstream from the confluence of the Niobrara, river stages have increased by about 4 feet during the period of 1977 to 1990 for discharges of 20,000 cfs to 40,000 cfs. The average rate of increase of about 0.3 feet per year during this period is a faster rate than that observed downstream of the Niobrara confluence. At Greenwood, approximately 20 miles upstream from the Niobrara confluence, the stages associated with discharges of 20,000 cfs to 40,000 cfs have not changed more than 1 foot between 1960 and 1990.

SUMMARY

In recent years, stages have generally shifted downward in the open river reaches from Gavins Point Dam to Omaha, Nebraska. Changing stage-discharge relationships along the Missouri River affect a multitude of water-related activities and facilities, resulting in both positive and negative impacts. Downward-moving stage trends have adversely impacted fish and wildlife as well as caused problems at fixed docks, boat ramps, off-channel marinas, water intakes, and in old oxbow lakes--particularly if they are still connected to the river. These potential problems were somewhat masked during the late 1970's and portions of the early 1980's due to the above normal inflows above and below the main stem reservoir system. However, the impacts became very obvious during the drought years 1987 through early 1993 when less than full service navigation flows were provided. Since no structural remedy by the Federal Government is imminent, this emerging problem will continue to require a good public relations effort to alert those affected to what is happening and how to adapt to the situation. Positive impacts include almost complete protection of lands from river erosion, a stable channel bank line for a wide variety of flood plain uses, commercial navigation with no need of channel dredging, and recreational boating.

In the tailwater areas, downstream from the projects, decreases in tailwater stage have generally been experienced, with the most noticeable stage reductions occuring at the Garrison, Fort Randall and Gavins Point projects. At these projects the tailwater stage has decreased by about 7 to 10 feet since closure of the dams. In the period from 1980 thru 1995, the rate of tailwater degradation had become more stable. The Gavins Point Project tailwater trends show a marked increase in the rate of degradation for the 1995 thru 1997 period. The exception to the tailwater stage reduction is occuring below Oahe, where the tailwater stage has increased by less than 1 foot.

Upward stage shifts are apparent for the higher discharges at all stations located along the navigation channel or in headwater areas, although at Kansas City the upward trend is only evident at flows exceeding 200,000 cfs. At Sioux City sufficient data are not available to reliably establish a trend at flows above 50,000 cfs. The upward trend is most apparent at Nebraska City and St. Joseph, where flows of 80,000 to 90,000 cfs now go overbank compared to bank full discharges of around 150,000 cfs about 30 years ago. The problem has worsened in the past 25 to 30 years due to increased utilization of low-lying flood plain areas. This reduced channel capacity makes flood control operation of the main stem and tributary reservoirs more difficult and less effective. However, the chances of getting flows in excess of the channel capacity have been greatly reduced due to the upstream reservoirs. Completion of the Federal agricultural levee system would only partially solve the problem, since many of the affected areas are between the Federal levee alignment and the river. Additional flood control reservoirs on intervening tributary streams would be needed for effective flood damage reductions in the areas most affected by the upward trending river stages.

The increases in stages at stations below Kansas City, for flow levels near bank full are limited to about 2 to 5 feet. Increases of this magnitude agree quite well with the values presented in referenced consultants' report of November 1955 relating to the effect of navigation structures on

river levels. The consultant board also expressed the opinion that the effect of the navigation works would be reduced above bank full flows and be lost in the greater effects of levee confinement, road fills, and other changes in the valley. Since the stage increases are greater at the higher flood discharges on the lower Missouri River, it seems apparent that the stage increases are due largely to factors other than navigation structures, primarily private levees and deposition of sediment on the floodplain above the navation channel at higher flows in recent years..

Stage trends at normal discharge levels, whether up or down, affect the design and subsequent functioning of the navigation and channel stabilization works. Many of these structures may be either too high or too low under today's stage-discharge conditions and a continuing reanalysis of the reference plane to which these structures are built and maintained is periodically required.

In the headwaters areas, an upward trend in river stages has occurred, primarily due to aggradation effects from sediment deposition. This trend will continue into the future and extend further upstream as more sediment is deposited in the delta areas.

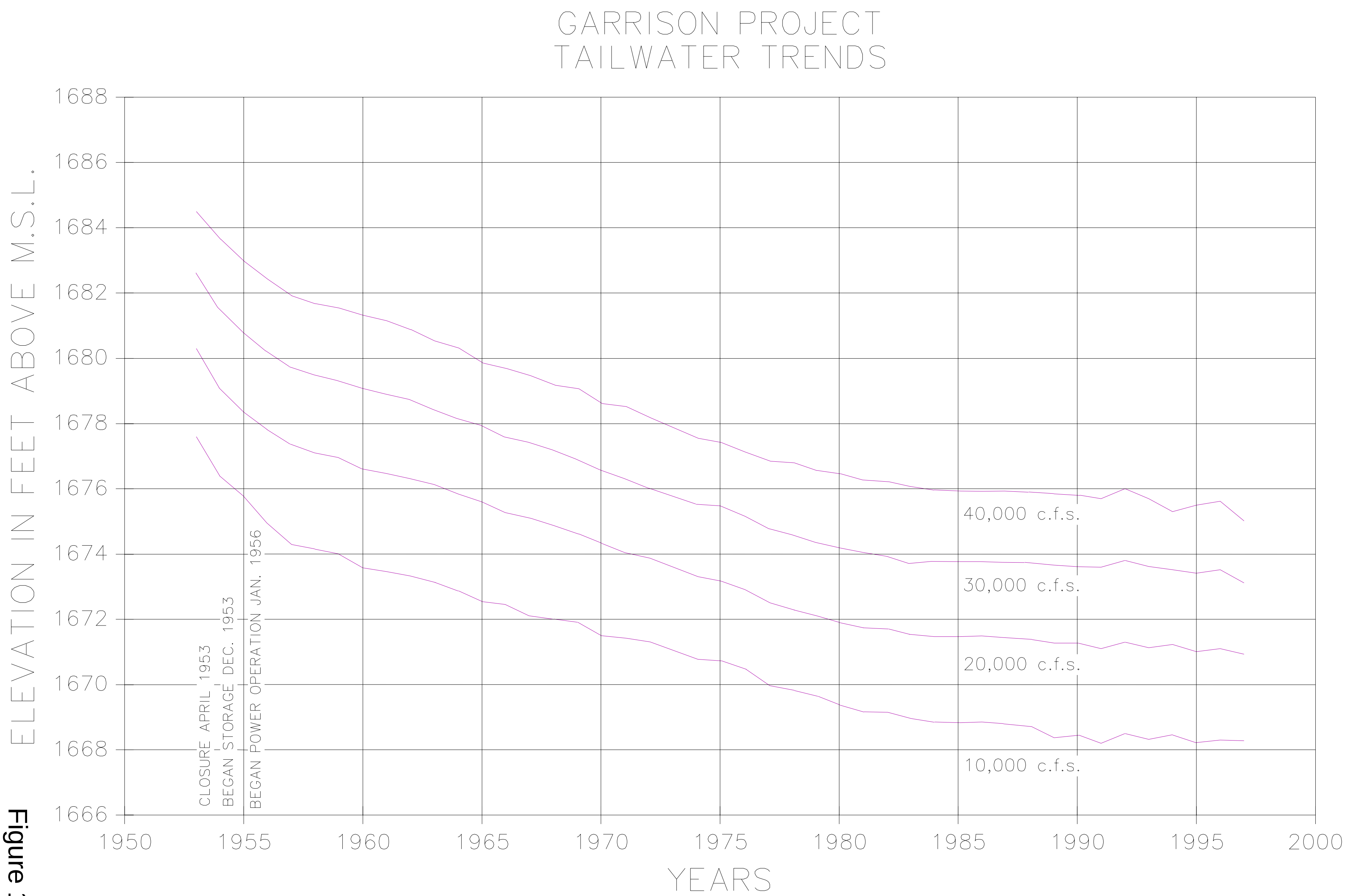
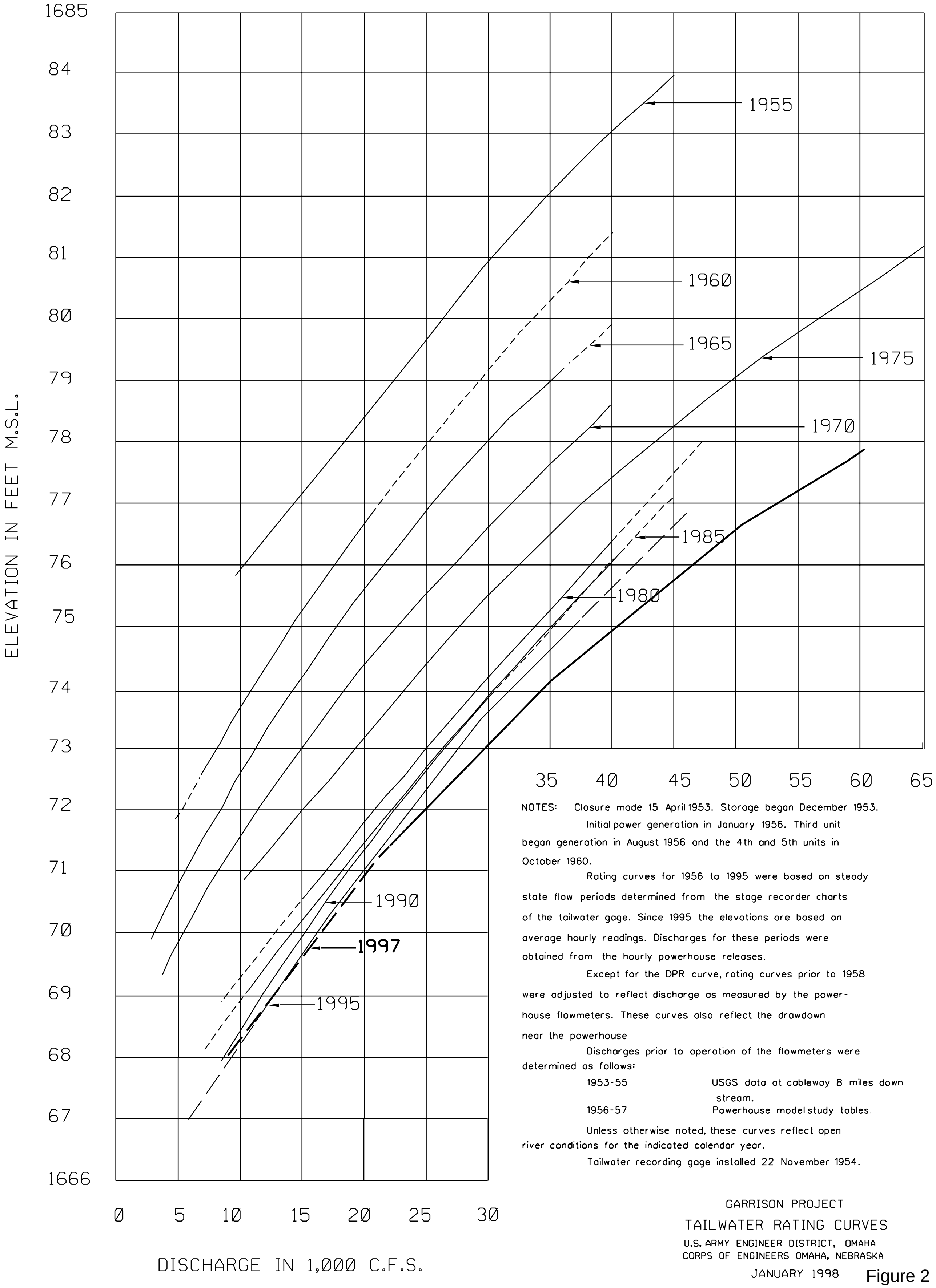

GARRISON PROJECT
TAILWATER TRENDS
ELEVATION IN FEET ABOVE M.S.L.
1688
1686
1684
1682
1680
1678
1676
1674
1672
1670
1668
1666
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEARS
CLOSURE APRIL 1953
BEGAN STORAGE DEC. 1953
BEGAN POWER OPERATION JAN. 1956
40,000 c.f.s.
30,000 c.f.s.
20,000 c.f.s.
10,000 c.f.s.

Figure 1



NOTES: Closure made 15 April 1953. Storage began December 1953. Initial power generation in January 1956. Third unit began generation in August 1956 and the 4th and 5th units in October 1960.

Rating curves for 1956 to 1995 were based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 the elevations are based on average hourly readings. Discharges for these periods were obtained from the hourly powerhouse releases.

Except for the DPR curve, rating curves prior to 1958 were adjusted to reflect discharge as measured by the power-house flowmeters. These curves also reflect the drawdown near the powerhouse

Discharges prior to operation of the flowmeters were determined as follows:

1953-55	USGS data at cableway 8 miles down stream.
1956-57	Powerhouse model study tables.

Unless otherwise noted, these curves reflect open river conditions for the indicated calendar year.

Tailwater recording gage installed 22 November 1954.

GARRISON PROJECT

TAILWATER RATING CURVES

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

JANUARY 1998

Figure 2

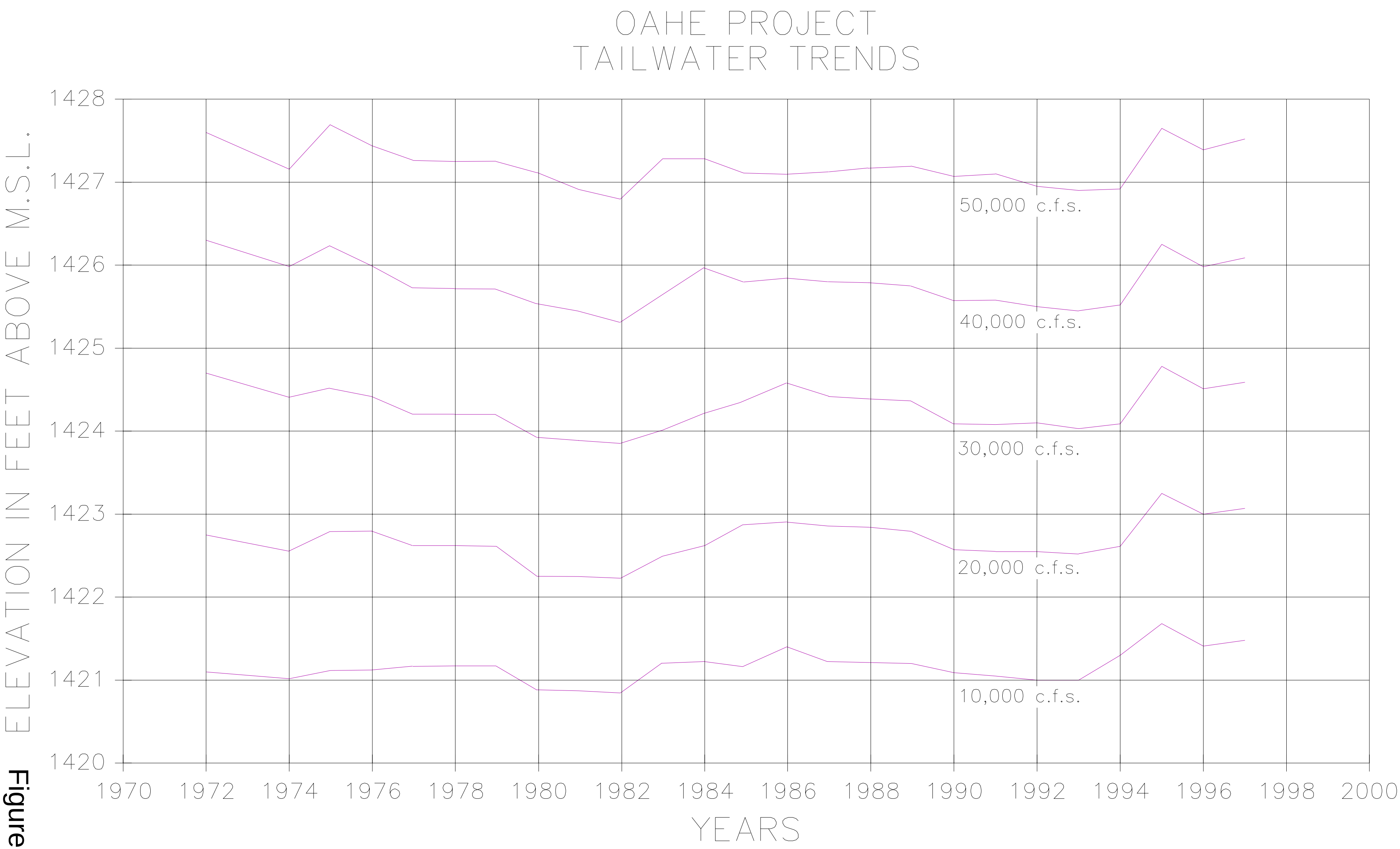
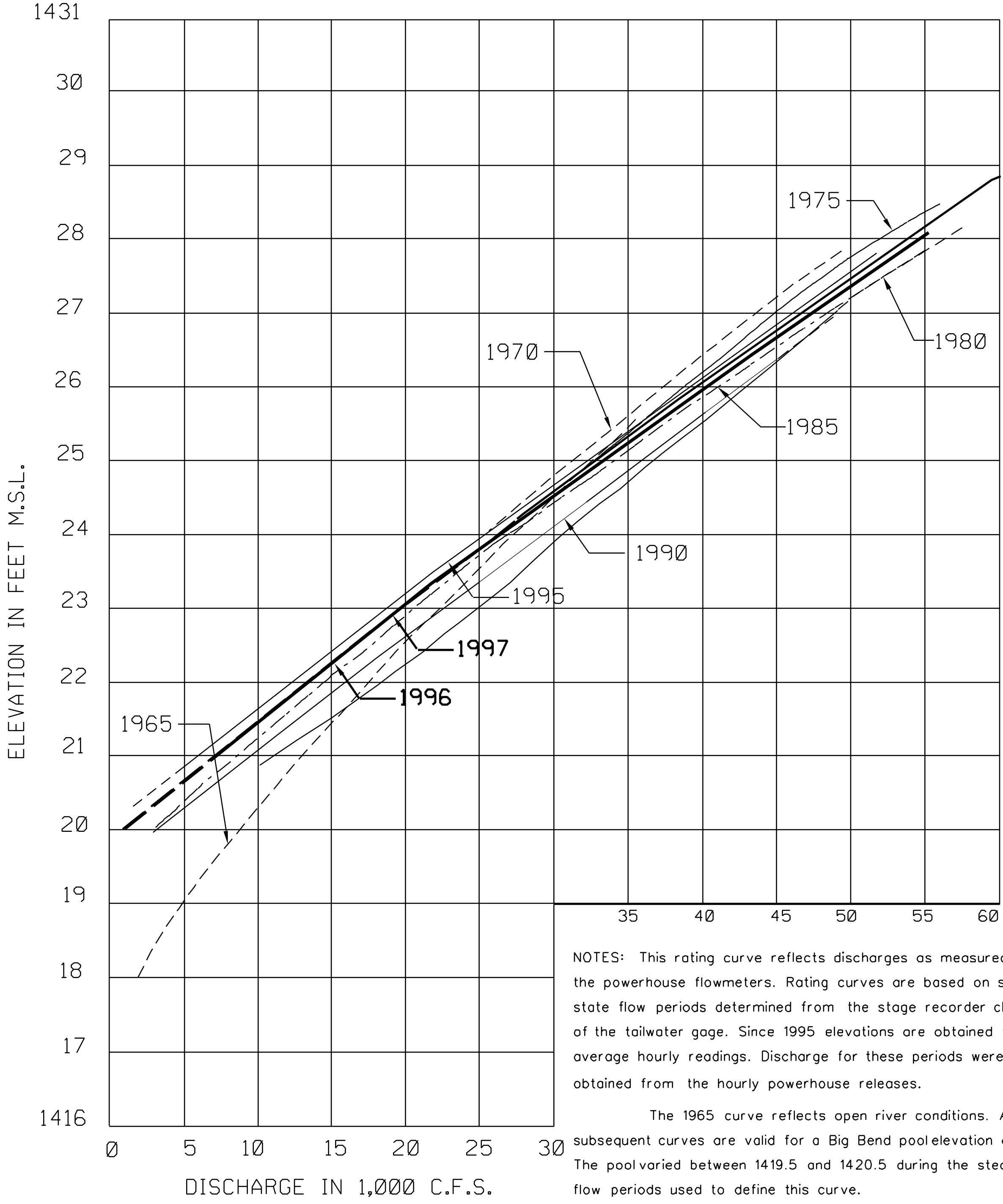

OAHE PROJECT
TAILWATER TRENDS
ELEVATION IN FEET ABOVE M.S.L.
1428
1427
1426
1425
1424
1423
1422
1421
1420
50,000 c.f.s.
40,000 c.f.s.
30,000 c.f.s.
20,000 c.f.s.
10,000 c.f.s.
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
YEARS

Figure 3



NOTES: This rating curve reflects discharges as measured by the powerhouse flowmeters. Rating curves are based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 elevations are obtained from average hourly readings. Discharge for these periods were obtained from the hourly powerhouse releases.

The 1965 curve reflects open river conditions. All subsequent curves are valid for a Big Bend pool elevation of 1420. The pool varied between 1419.5 and 1420.5 during the steady state flow periods used to define this curve.

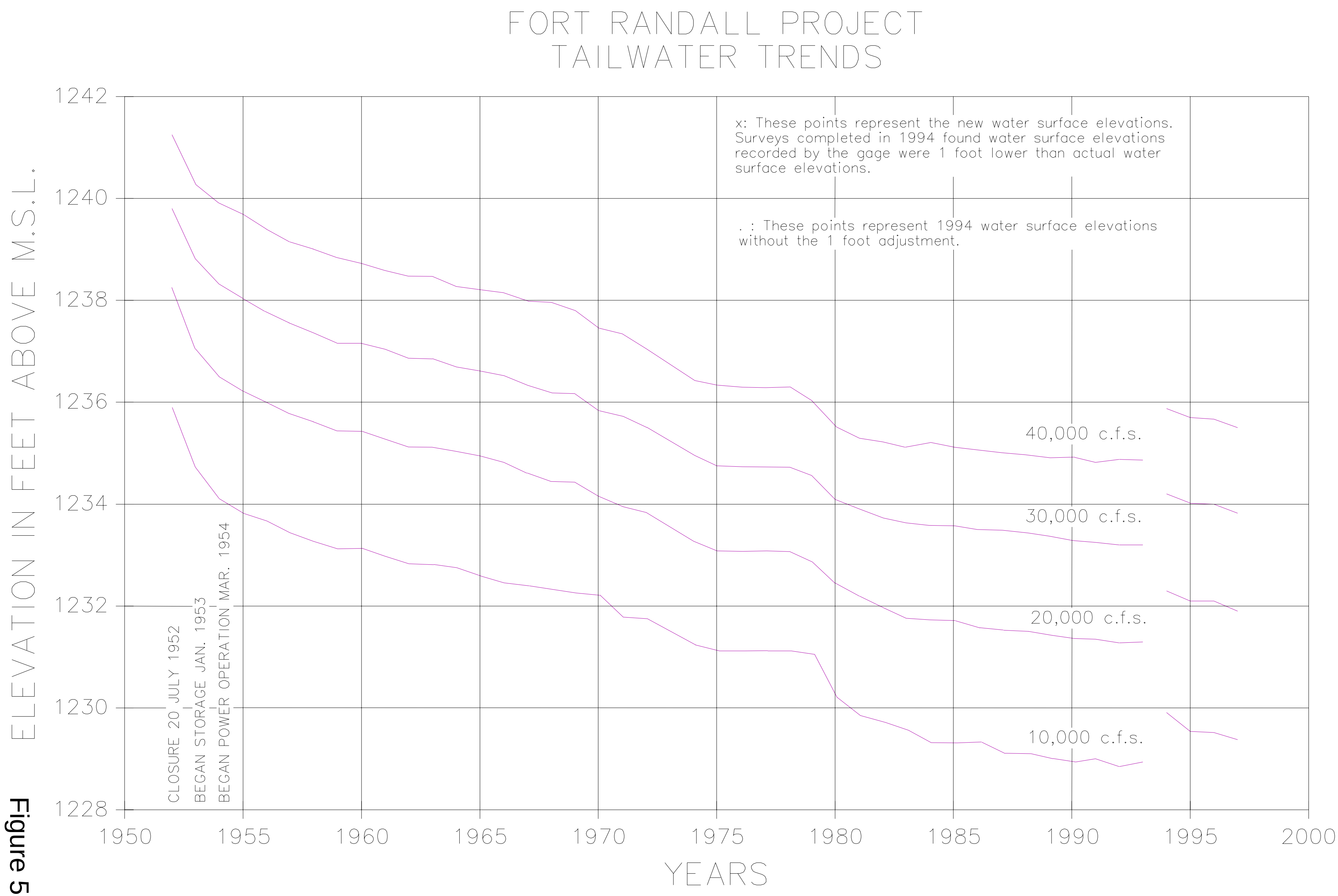
The construction of channel block No. 6 was completed 15 June 1967. An extension of channel block No. 6 to River Island was completed 12 July 1970.

OAHE PROJECT

POWERHOUSE

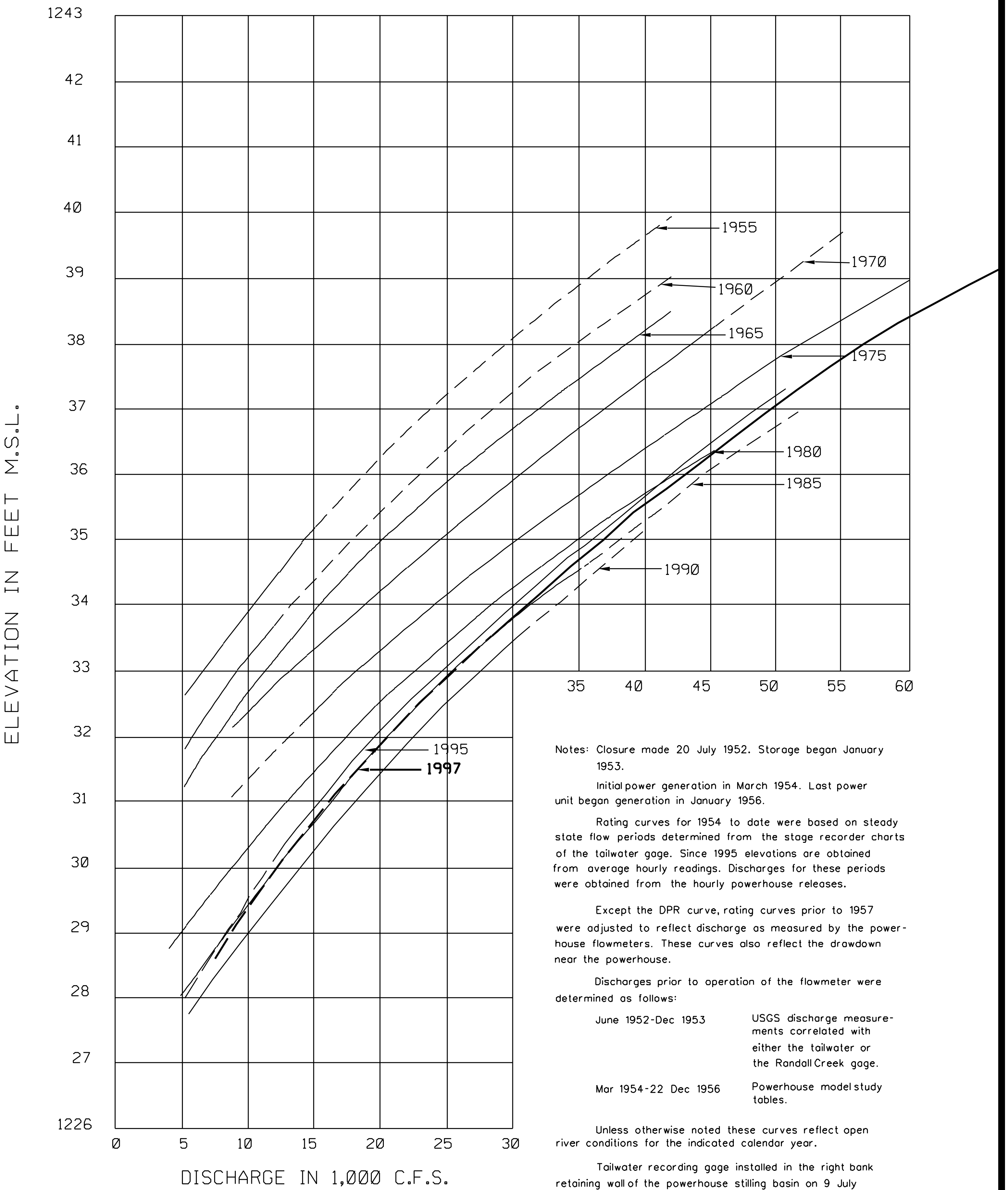
TAILWATER RATING CURVES
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JANUARY 1998

Figure 4



FORT RANDALL PROJECT
TAILWATER TRENDS
x: These points represent the new water surface elevations. Surveys completed in 1994 found water surface elevations recorded by the gage were 1 foot lower than actual water surface elevations.
. : These points represent 1994 water surface elevations without the 1 foot adjustment.
40,000 c.f.s.
30,000 c.f.s.
20,000 c.f.s.
10,000 c.f.s.
CLOSURE 20 JULY 1952
BEGAN STORAGE JAN. 1953
BEGAN POWER OPERATION MAR. 1954
ELEVATION IN FEET ABOVE M.S.L.
1242
1240
1238
1236
1234
1232
1230
1228
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEARS

Figure 5



Notes: Closure made 20 July 1952. Storage began January 1953.

Initial power generation in March 1954. Last power unit began generation in January 1956.

Rating curves for 1954 to date were based on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 elevations are obtained from average hourly readings. Discharges for these periods were obtained from the hourly powerhouse releases.

Except the DPR curve, rating curves prior to 1957 were adjusted to reflect discharge as measured by the powerhouse flowmeters. These curves also reflect the drawdown near the powerhouse.

Discharges prior to operation of the flowmeter were determined as follows:

June 1952-Dec 1953	USGS discharge measurements correlated with either the tailwater or the Randall Creek gage.
Mar 1954-22 Dec 1956	Powerhouse model study tables.

Unless otherwise noted these curves reflect open river conditions for the indicated calendar year.

Tailwater recording gage installed in the right bank retaining wall of the powerhouse stilling basin on 9 July 1952.

* 1995 curve shows an adjustment made to the datum. Not an aggradation trend. See trend plot.

FORT RANDALL PROJECT

TAILWATER RATING CURVES

U.S.ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA.

JANUARY 1998

Figure 6

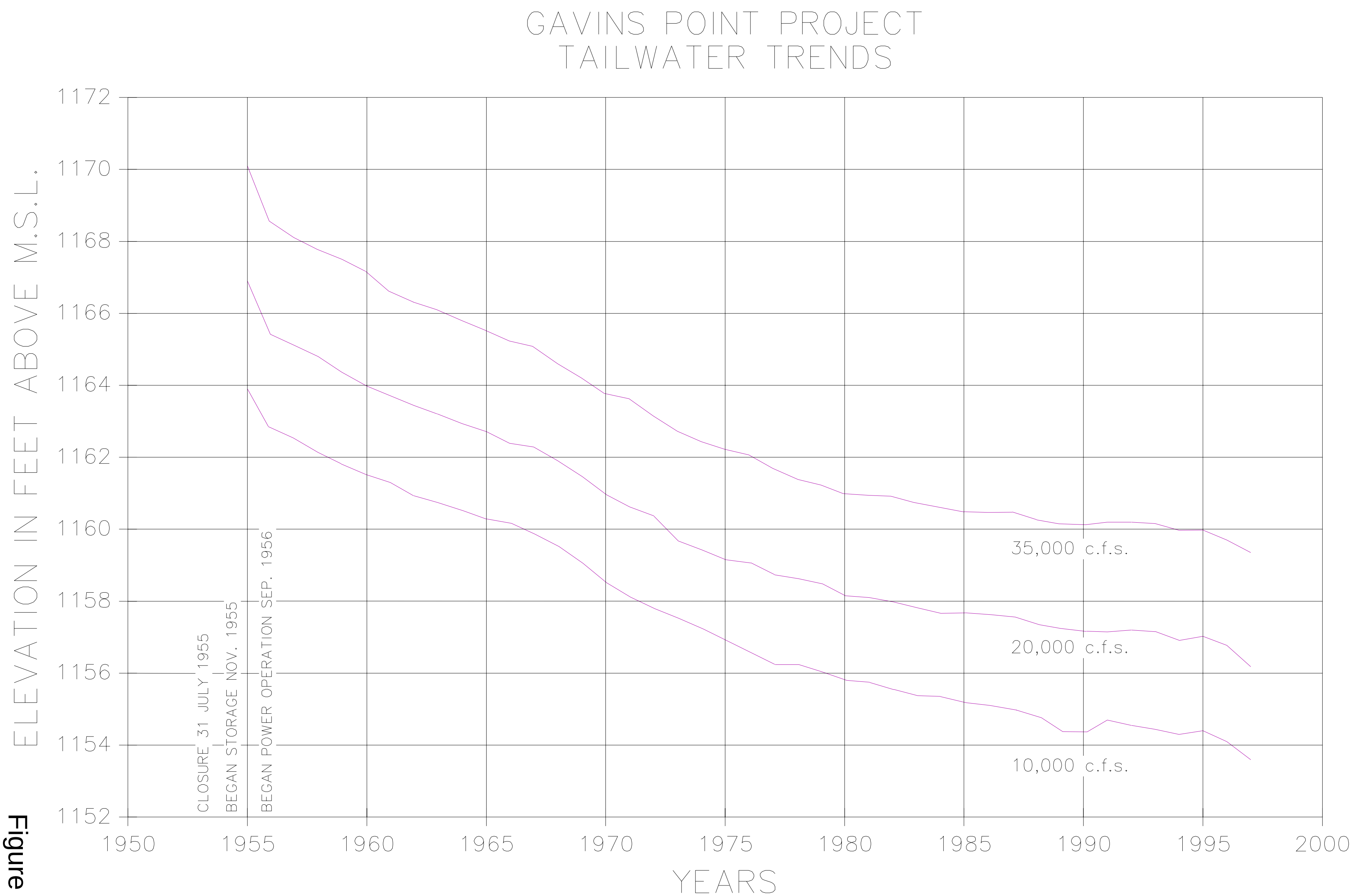
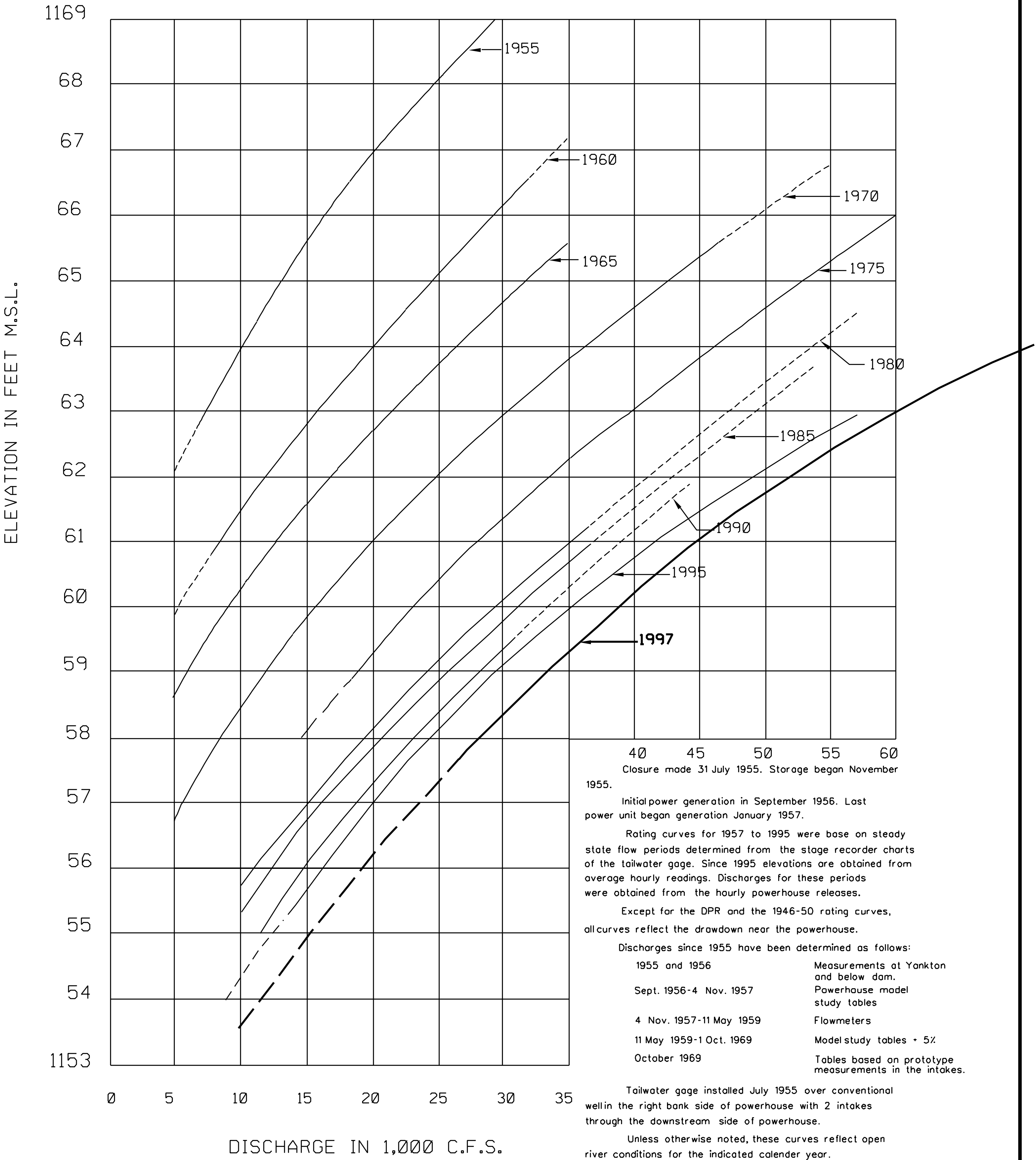

GAVINS POINT PROJECT
TAILWATER TRENDS
ELEVATION IN FEET ABOVE M.S.L.
1172
1170
1168
1166
1164
1162
1160
1158
1156
1154
1152
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
YEARS
CLOSURE 31 JULY 1955
BEGAN STORAGE NOV. 1955
BEGAN POWER OPERATION SEP. 1956
35,000 c.f.s.
20,000 c.f.s.
10,000 c.f.s.

Figure 7



Closure made 31 July 1955. Storage began November 1955.

Initial power generation in September 1956. Last power unit began generation January 1957.

Rating curves for 1957 to 1995 were base on steady state flow periods determined from the stage recorder charts of the tailwater gage. Since 1995 elevations are obtained from average hourly readings. Discharges for these periods were obtained from the hourly powerhouse releases.

Except for the DPR and the 1946-50 rating curves, all curves reflect the drawdown near the powerhouse.

Discharges since 1955 have been determined as follows:

1955 and 1956	Measurements at Yankton and below dam.
Sept. 1956-4 Nov. 1957	Powerhouse model study tables
4 Nov. 1957-11 May 1959	Flowmeters
11 May 1959-1 Oct. 1969	Model study tables + 5%
October 1969	Tables based on prototype measurements in the intakes.

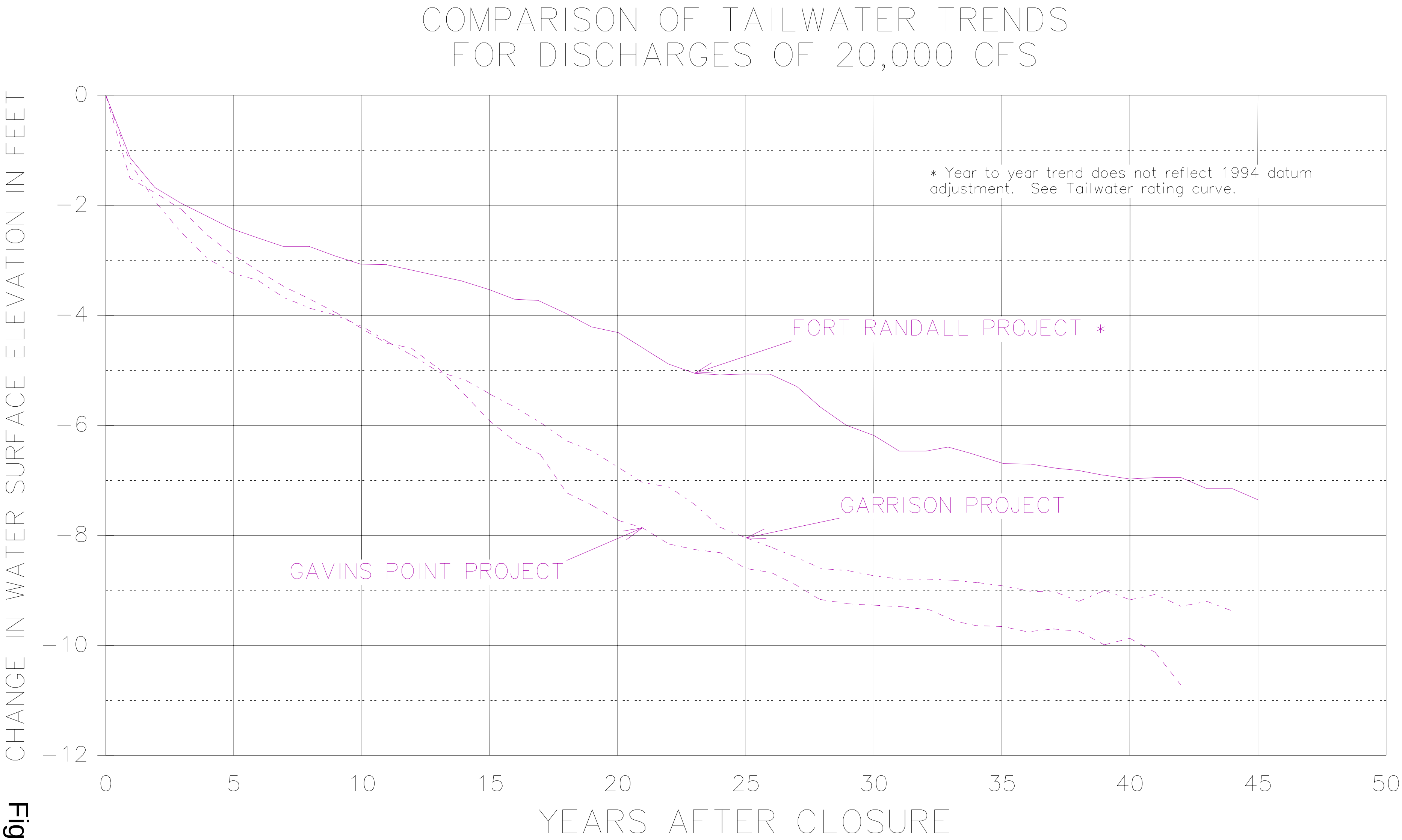
Tailwater gage installed July 1955 over conventional well in the right bank side of powerhouse with 2 intakes through the downstream side of powerhouse.

Unless otherwise noted, these curves reflect open river conditions for the indicated calender year.

GAVINS POINT PROJECT
TAILWATER RATING CURVES

U.S. ARMY ENGINEERS DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
JANUARY 1998

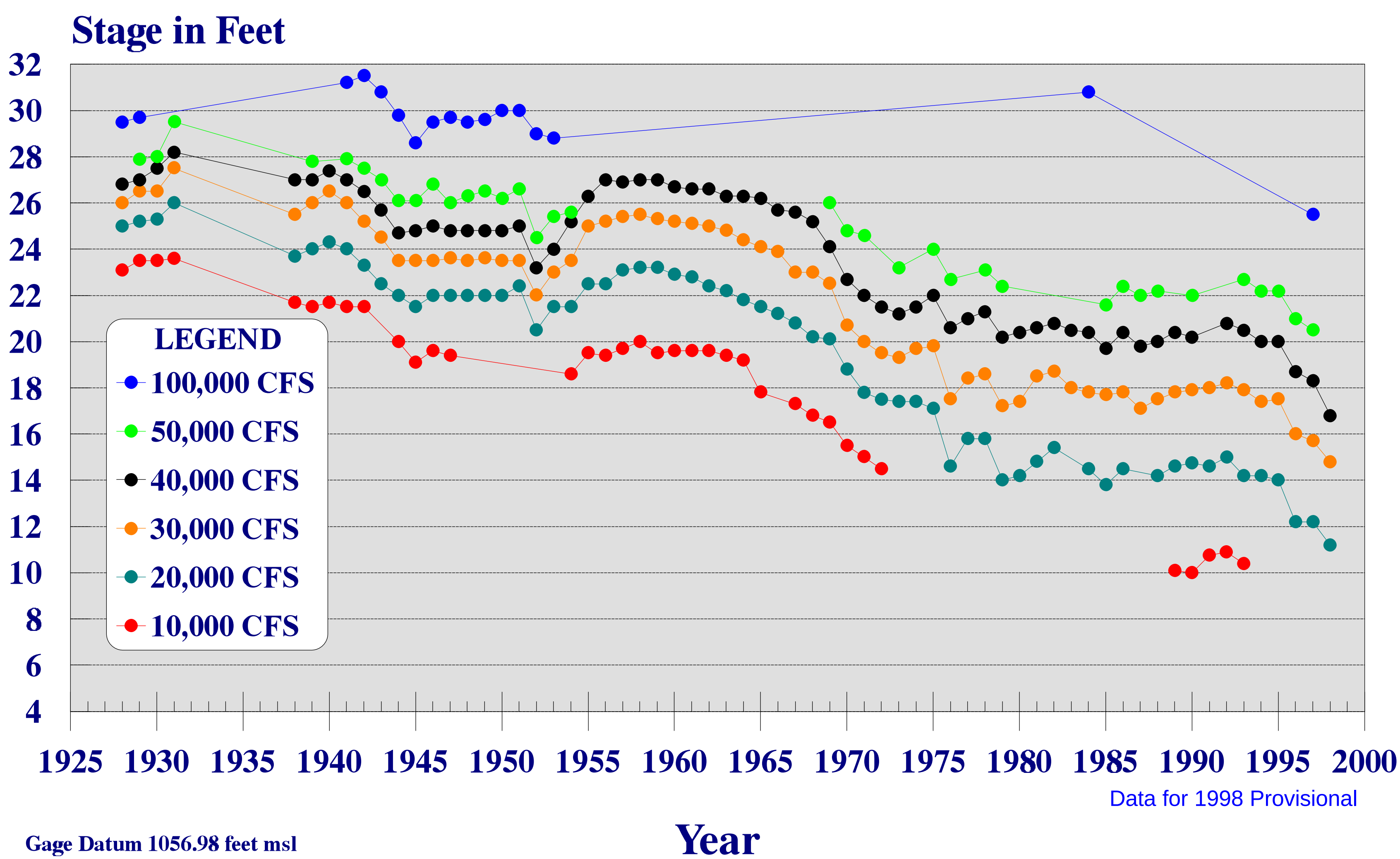
Figure 8



COMPARISON OF TAILWATER TRENDS
FOR DISCHARGES OF 20,000 CFS
CHANGE IN WATER SURFACE ELEVATION IN FEET
0
-2
-4
-6
-8
-10
-12
0
5
10
15
20
25
30
35
40
45
50
YEARS AFTER CLOSURE
* Year to year trend does not reflect 1994 datum adjustment. See Tailwater rating curve.
FORT RANDALL PROJECT *
GARRISON PROJECT
GAVINS POINT PROJECT

Figure 9

Missouri River Stage Trends
at Sioux City, Iowa

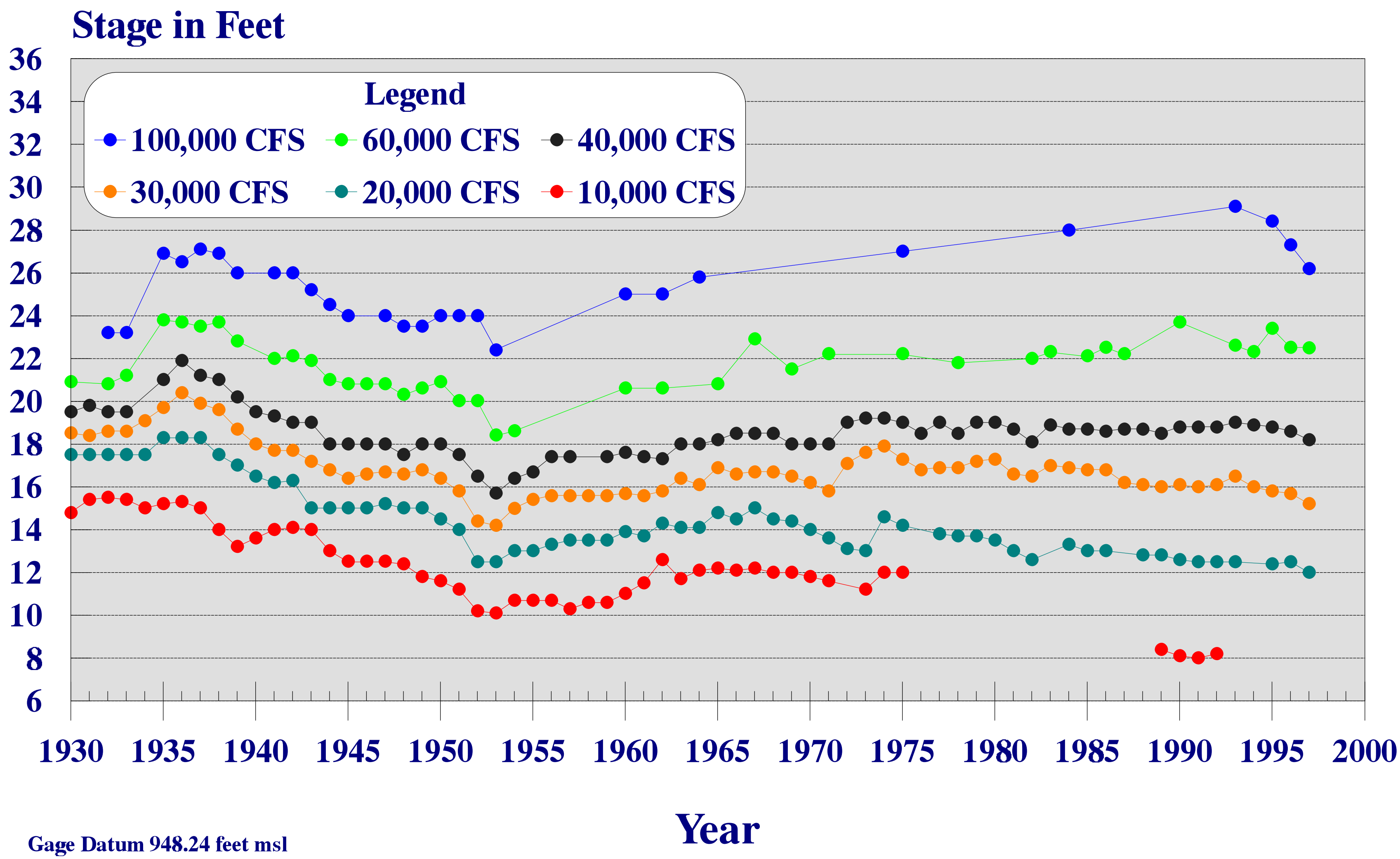


Gage Datum 1056.98 feet msl
Flood Stage 30 feet
River Mile 732.3

2/98

Figure 10

Missouri River Stage Trends at Omaha, Nebraska

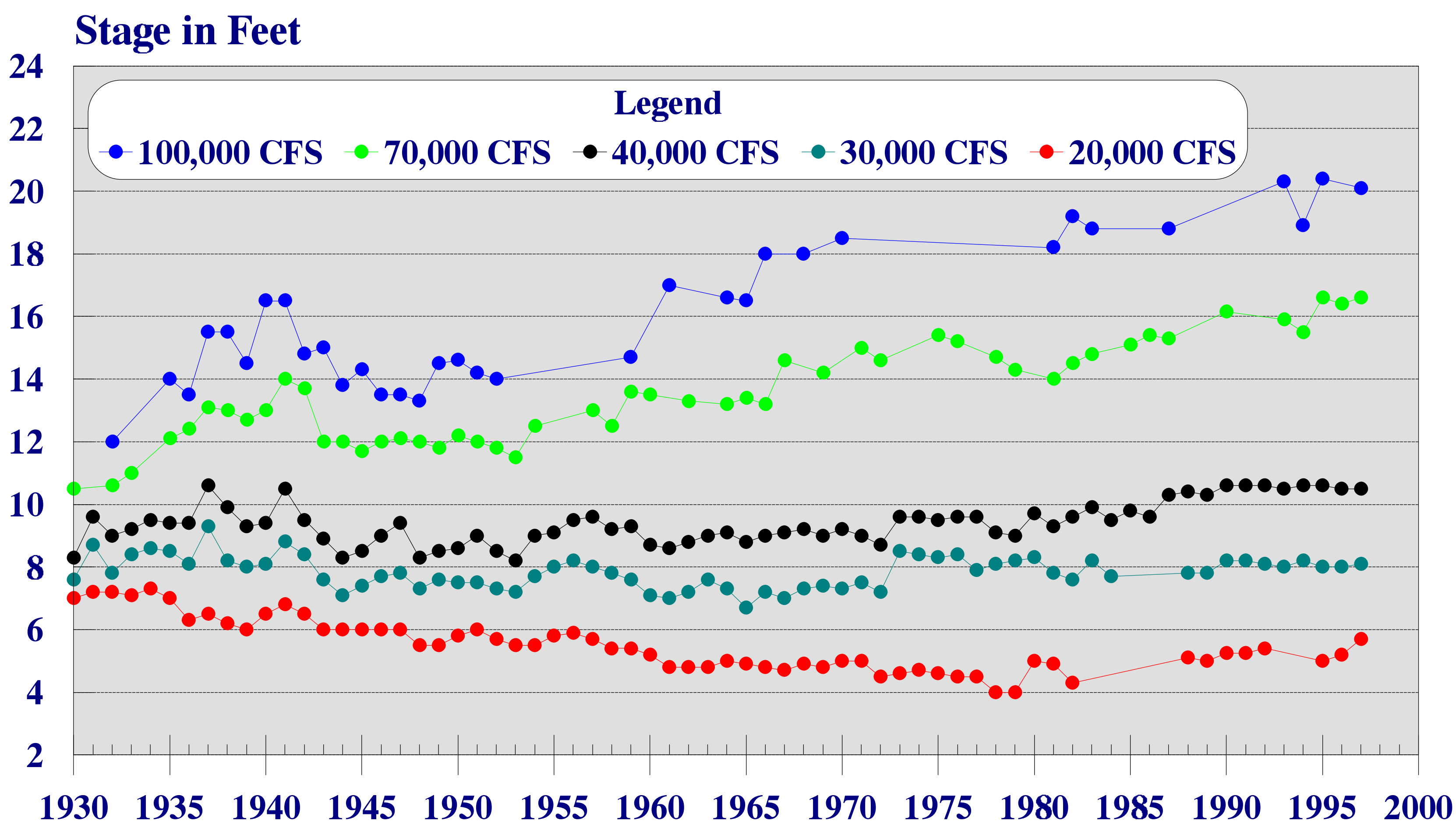


Gage Datum 948.24 feet msl
Flood Stage 29 feet
River Mile 615.9

2/98

Figure 11

Missouri River Stage Trends
at Nebraska City, Nebraska

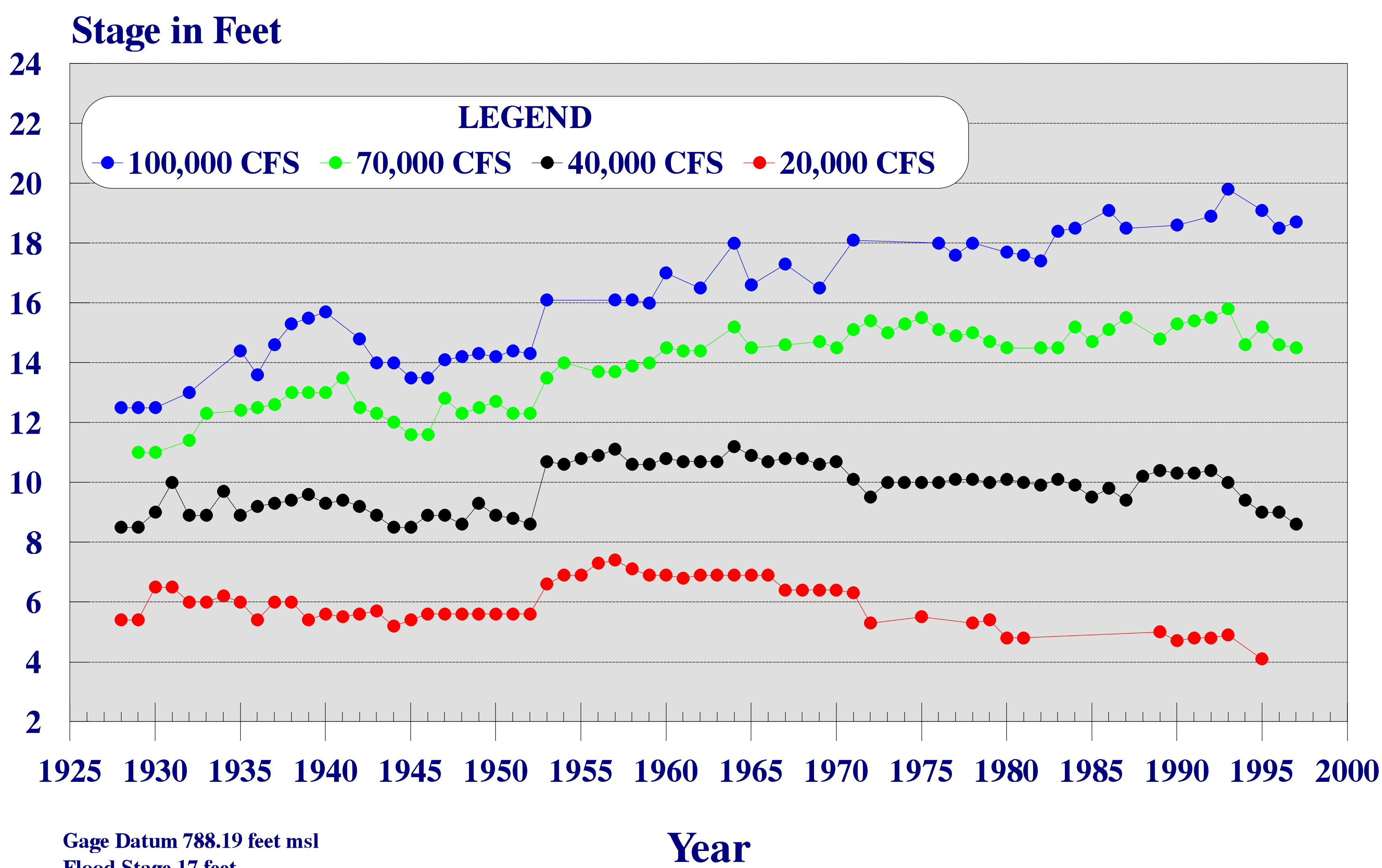


Gage Datum 905.36 feet msl
Flood Stage 18 feet
River Mile 562.6

2/98

Figure 12

Missouri River Stage Trends at St. Joseph, Missouri

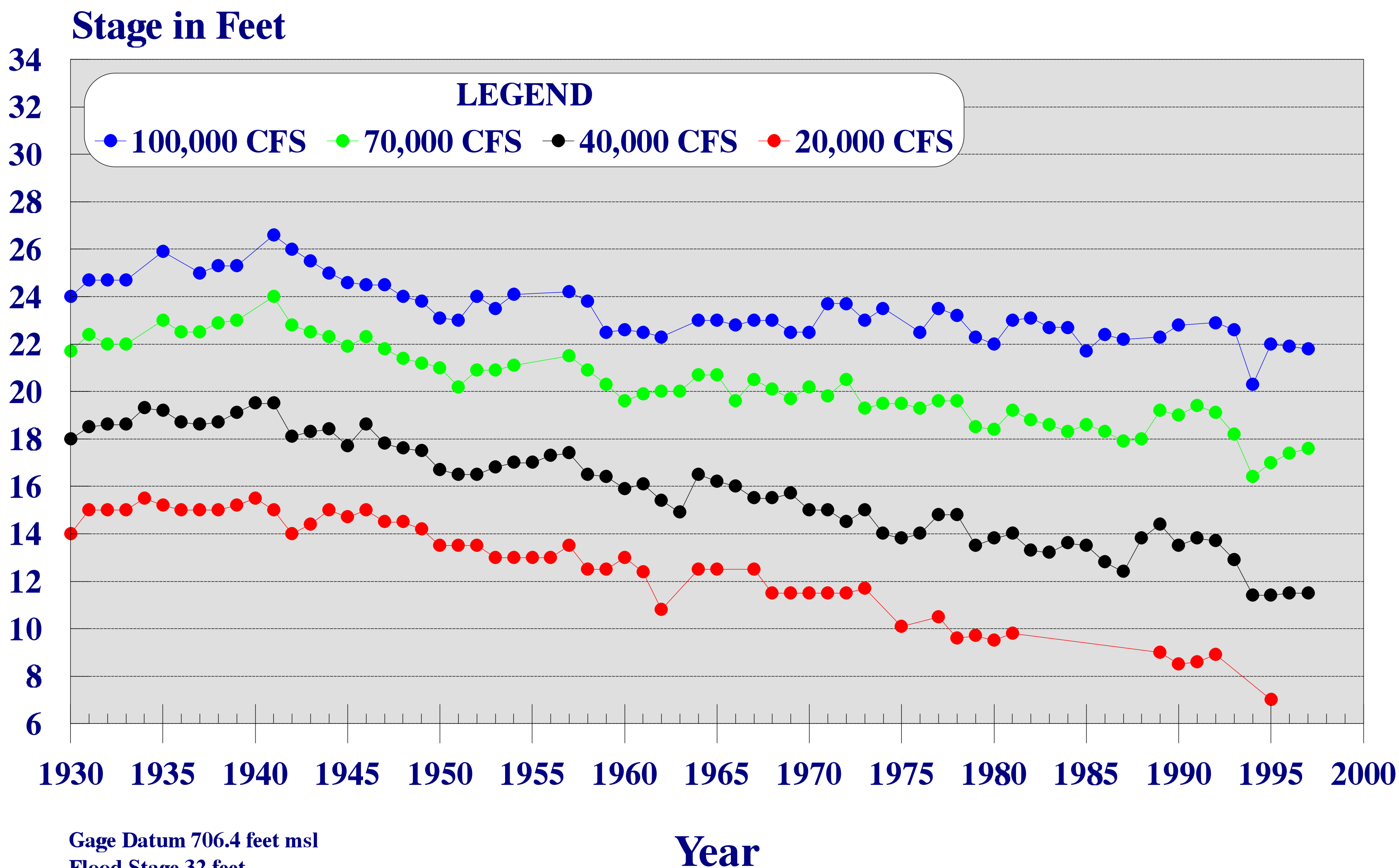


Gage Datum 788.19 feet msl
Flood Stage 17 feet
River Mile 448.2

2/98

Figure 13

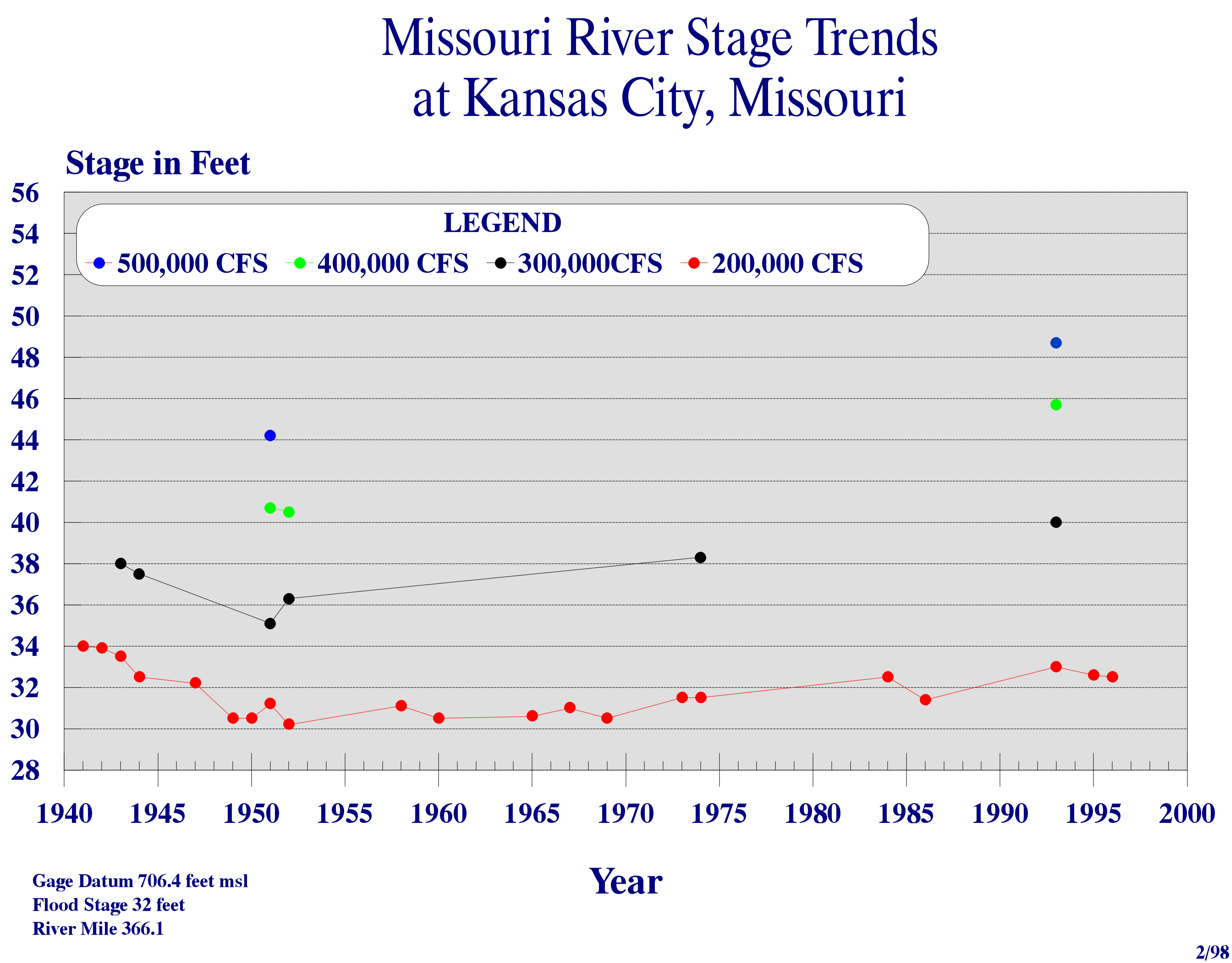
Missouri River Stage Trends at Kansas City, Missouri



Gage Datum 706.4 feet msl
Flood Stage 32 feet
River Mile 366.1

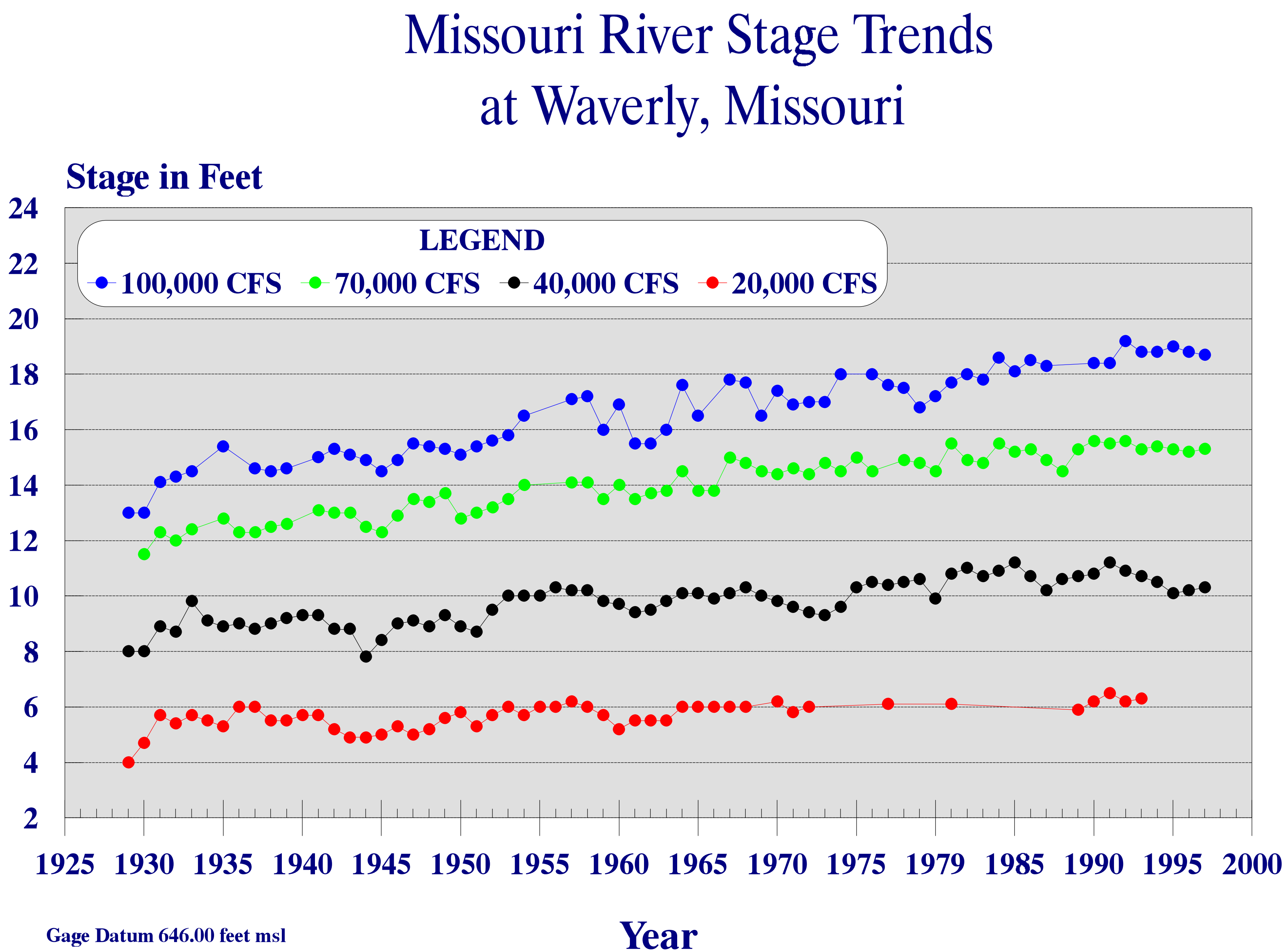
2/98

Figure 14



Missouri River Stage Trends
at Kansas City, Missouri
Stage in Feet
LEGEND
500,000 CFS
400,000 CFS
300,000CFS
200,000 CFS
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year
Gage Datum 706.4 feet msl
Flood Stage 32 feet
River Mile 366.1
2/98

Figure 15

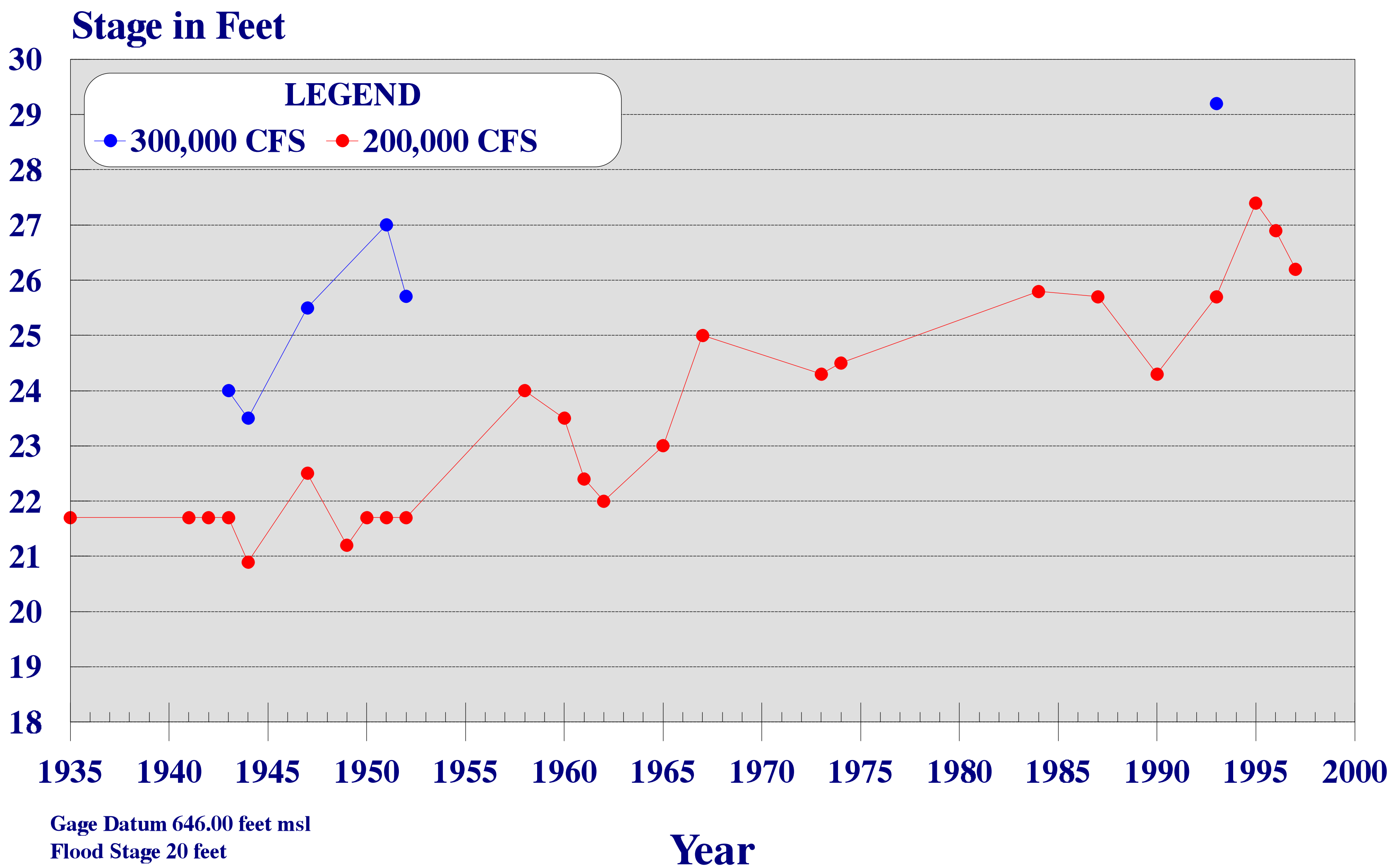


Gage Datum 646.00 feet msl
Flood Stage 20 feet
River Mile 293.4

2/98

Figure 16

Misssouri River Stage Trends at Waverly, Missouri

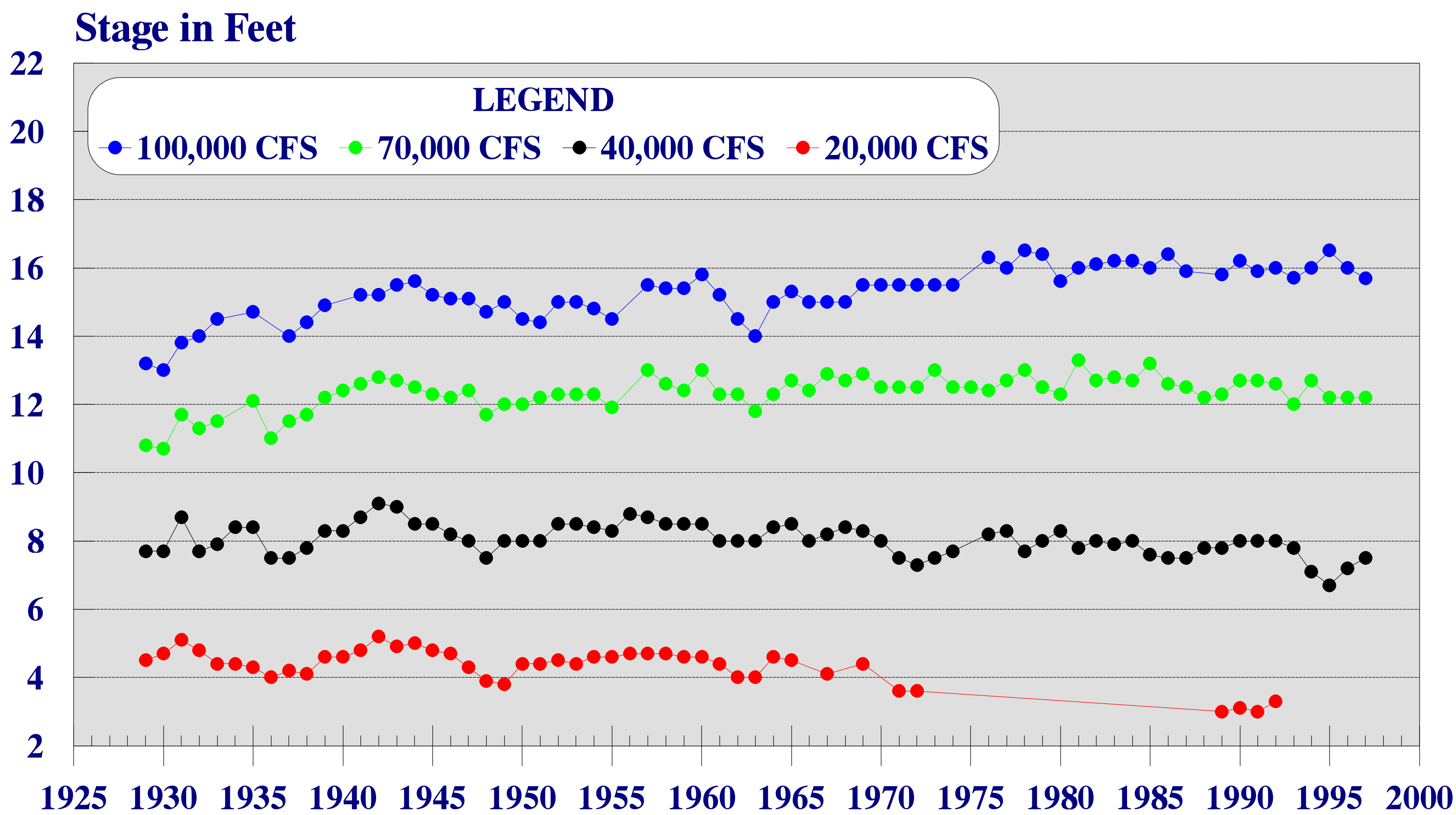


Gage Datum 646.00 feet msl
Flood Stage 20 feet
River Mile 293.4

2/98

Figure 17

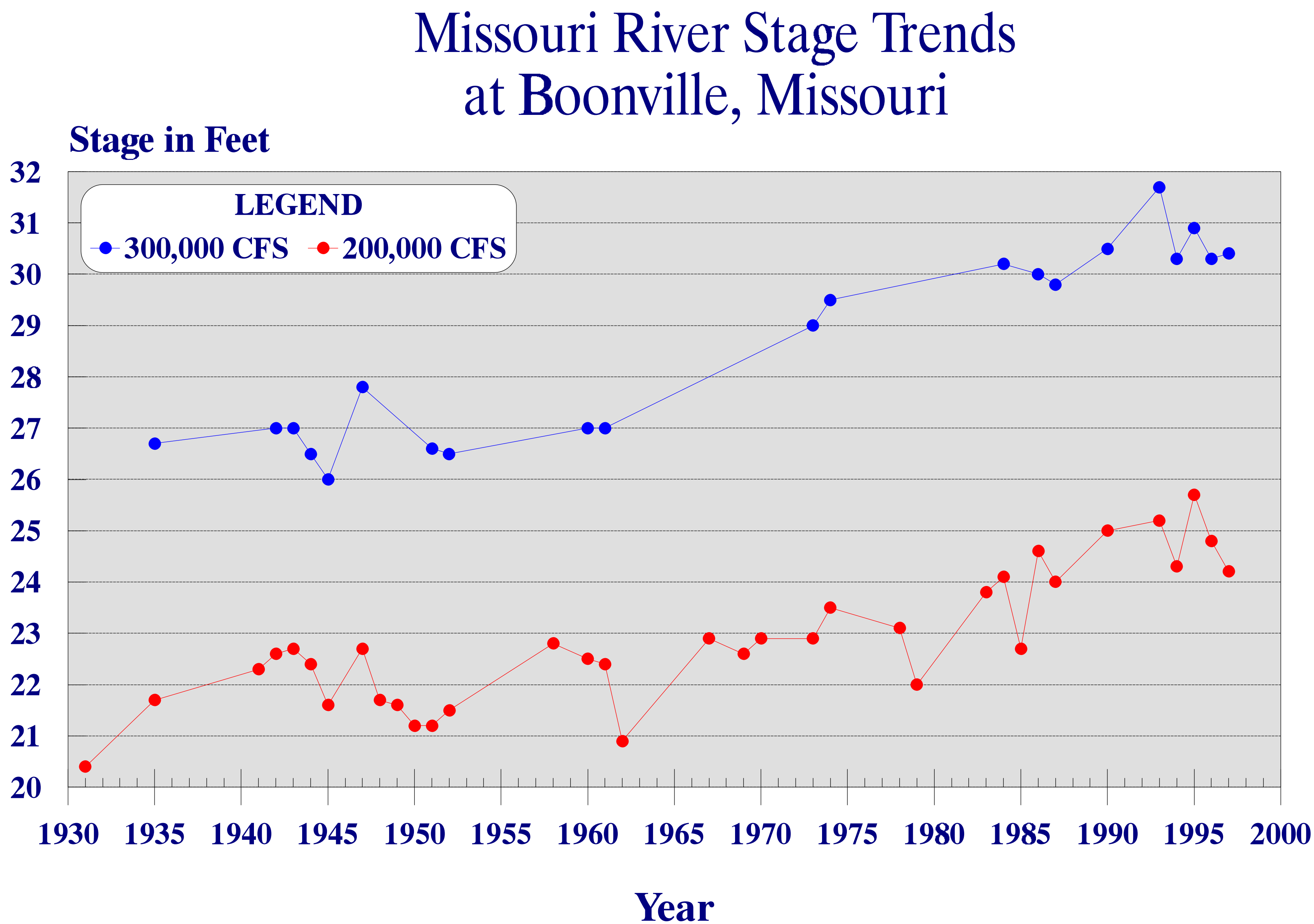
Missouri River Stage Trends at Boonville, Missouri



Gage Datum 565.42 feet msl
Flood Stage 21 feet
River Mile 197.1

2/98

Figure 18

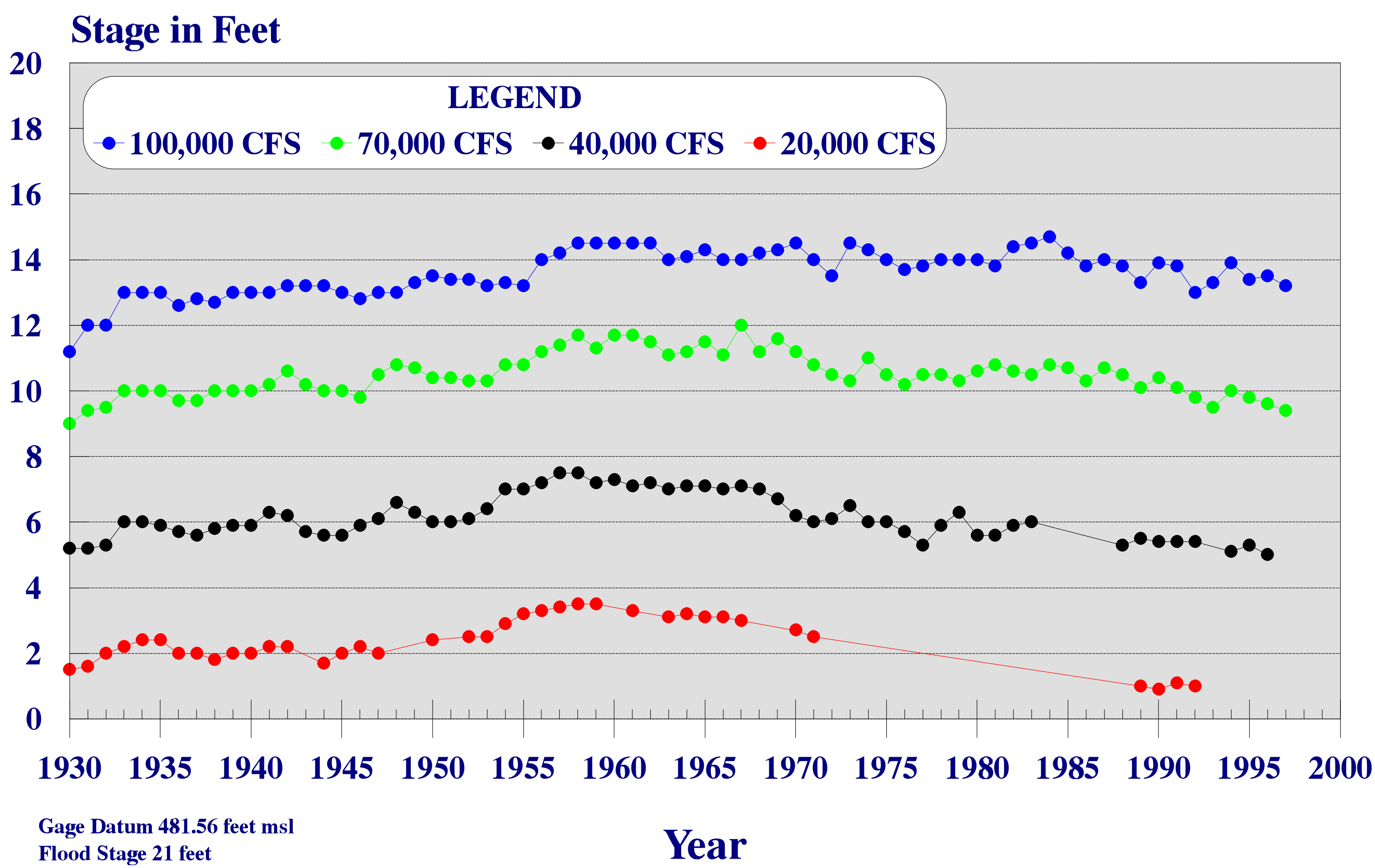


Gage Datum 565.42 feet msl
Flood Stage 21 feet
River Mile 197.1

2/98

Figure 19

Missouri River Stage Trends at Hermann, Missouri

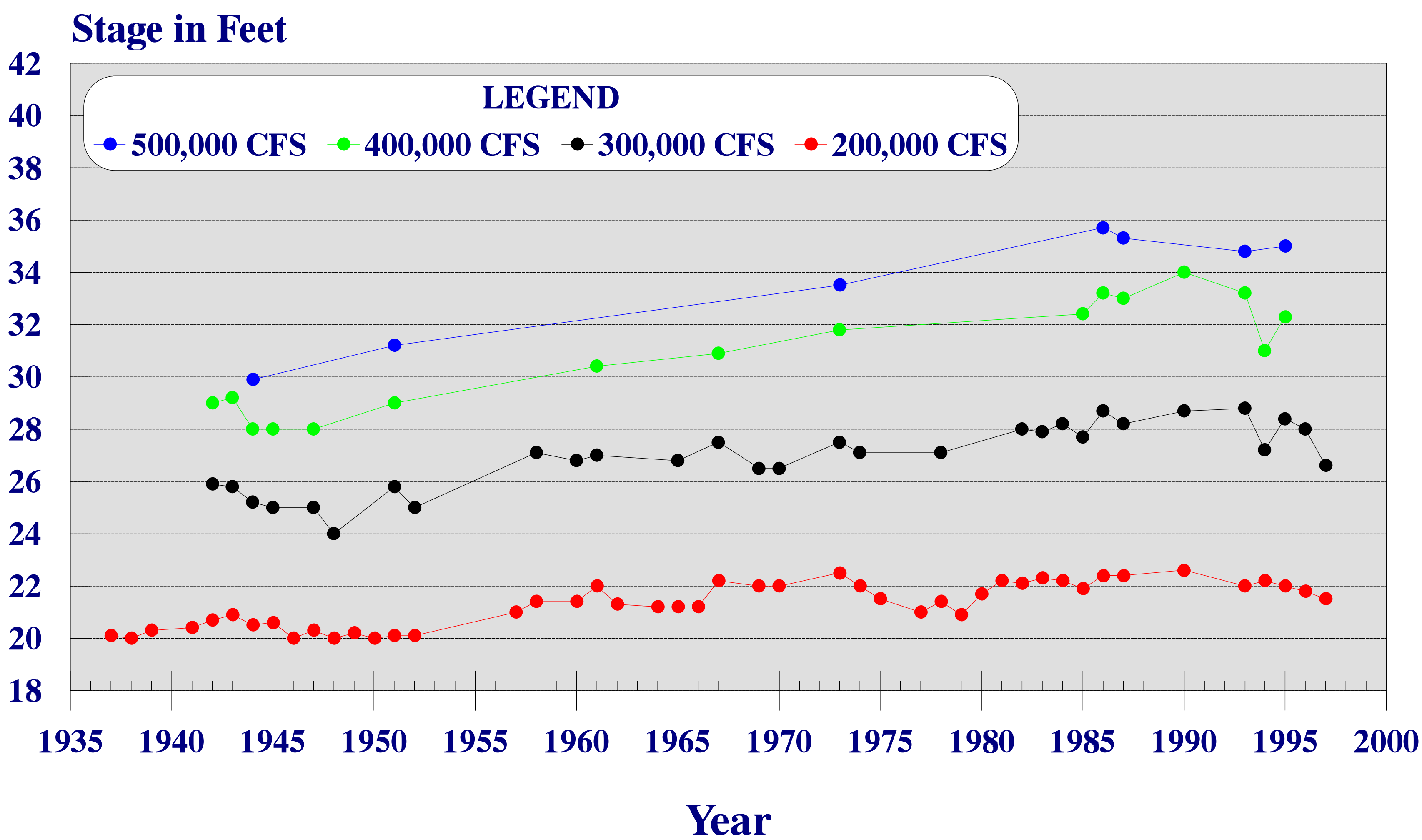


Gage Datum 481.56 feet msl
Flood Stage 21 feet
River Mile 97.9

2/98

Figure 20

Missouri River Stage Trends
at Hermann, Missouri

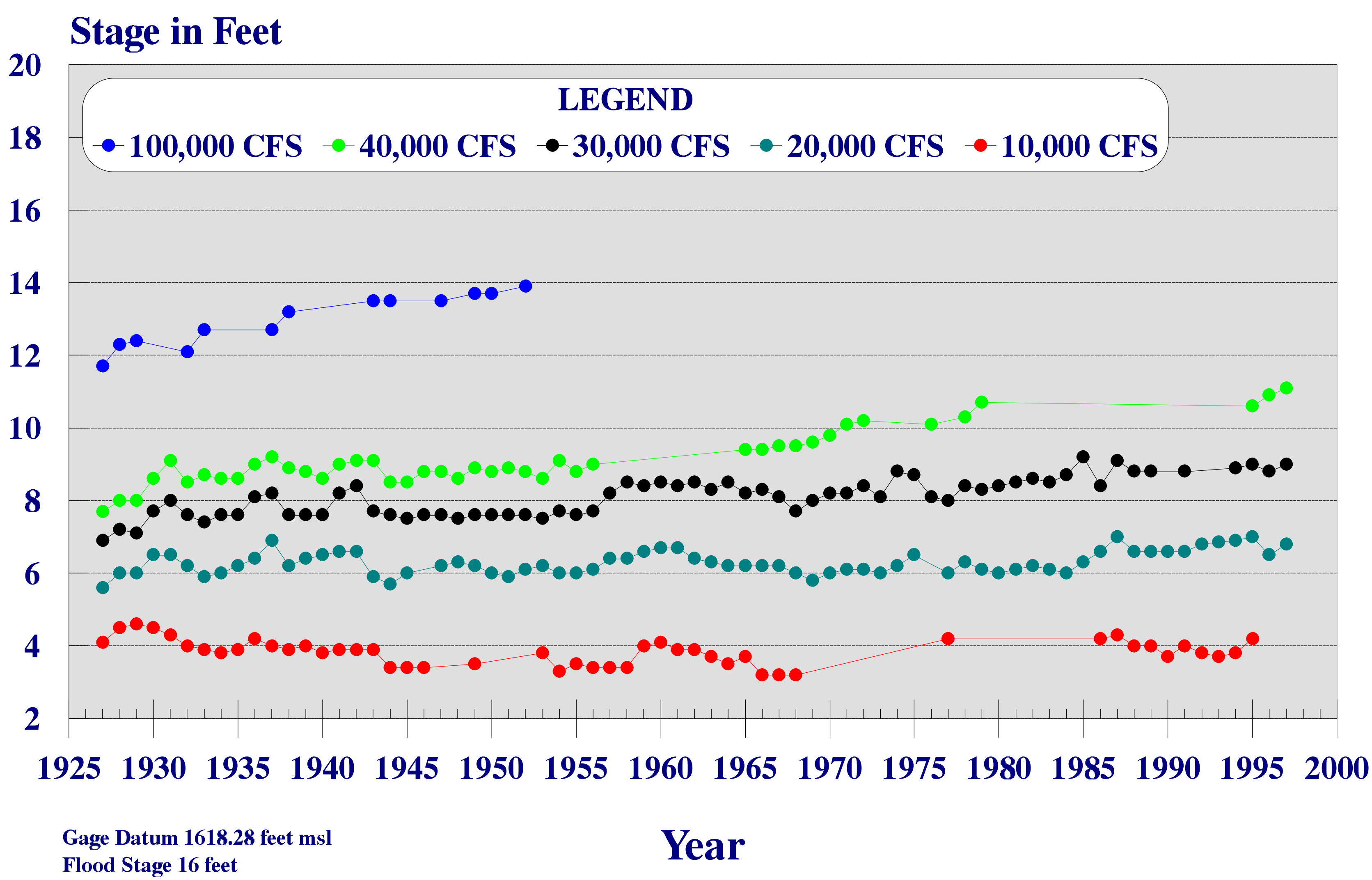


Gage Datum 481.56 feet msl
Flood Stage 21 feet
River Mile 97.9

2/98

Figure 21

Missouri River Stage Trends at Bismarck, North Dakota



Gage Datum 1618.28 feet msl
Flood Stage 16 feet
River Mile 1314.5

Figure 22

2/98